SU-SEL-70-035

A VHF Polarimeter

by

William E. Faulkerson

June 1970

Technical Report No. 35

Prepared under
National Aeronautics and Space
Administration Grant NGL 05-020-014

RADIOSCIENCE LABORATORY

STANFORD ELECTRONICS LABORATORIES

STANFORD UNIVERSITY · STANFORD, CALIFORNIA

SEL-70-035

A VHF POLARIMETER

by

William E. Faulkerson

June 1970

Technical Report No. 35

Prepared under

National Aeronautics and Space
Administration Grant NGL 05-020-014

Radioscience Laboratory
Stanford Electronics Laboratories
Stanford University Stanford, California

ABSTRACT

A continuous record of ionospheric electron content over a fixed raypath can be obtained by measuring the Faraday rotation of linearly polarized VHF transmissions from geostationary satellites. A polarimeter system is described, which consists of a rotating antenna and a receiver/phase-meter instrument that can be economically constructed to perform this measurement. Details of construction, alignment, and operation are discussed.

CONTENTS

CONTENTS (Cont)

ILLUSTRATIONS

ILLUSTRATIONS (Cont)

ACKNOWLEDGMENT

I wish to express special thanks to Mr. H. T. Howard for his technical advice and encouragement during the development of the polarimeter. I am also indebted to Mr. S. C. Hall for the design of the tripod assembly and field testing of the system.

Development of this equipment was supported by the National Aeronautics and Space Administration.

Chapter I

INTRODUCTION

When the Stanford Center for Radar Astronomy initiated measurement of the interplanetary electron content using the Pioneer series of deep space probes, it was necessary to perform a simultaneous independent measurement of the substantial contribution of the ionosphere to derive the interplanetary values. Early techniques used Faraday rotation and differential doppler data obtained from VHF transmissions of the Explorer 22 and 27 satellites. These data were of limited value because of the small number of ionospheric points obtained when compared to the total time that Pioneer was observed. The situation improved considerably with the availability of VHF transmissions from geostationary satellites of the Syncom and ATS series. By measuring the Faraday rotation of these linearly polarized signals, the ionospheric electron content can be continuously recorded.

The Pioneer experiment and other ionospheric research being conducted at Stanford University prompted the development of inexpensive polarimeters, the latest of which is described in this report; Figs. 1 and 2 are photographs of its rotating antenna system and the receiver/phase meter instrument. Sufficient information concerning the design, construction, alignment, and operation is provided in the following chapters to allow duplication of the system which then can be employed in many areas of research where the ionosphere is involved.

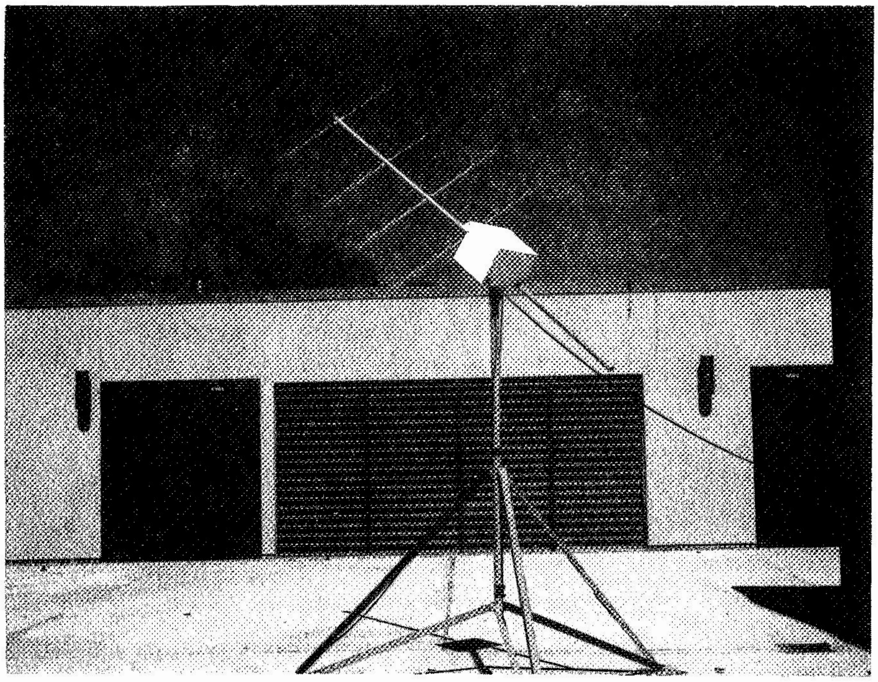


Fig. 1. ANTENNA SYSTEM.

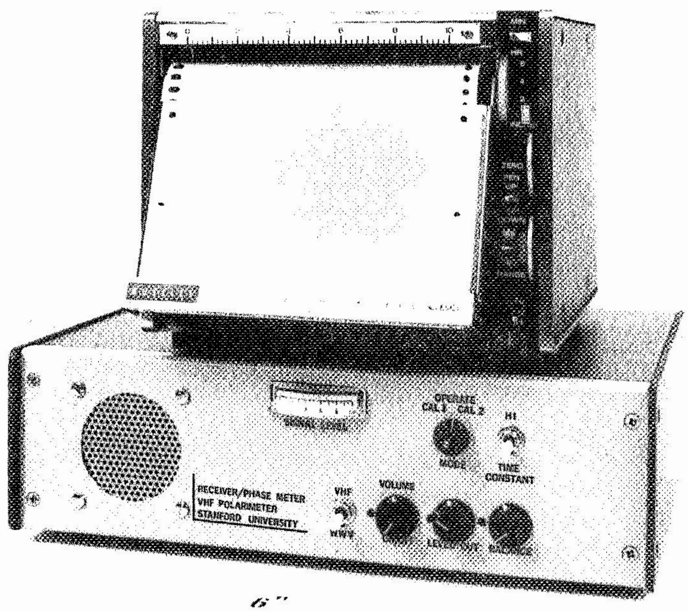


Fig. 2. RECEIVER/PHASE-METER INSTRUMENT.

Chapter II

THE VHF POLARIMETER

The availability of linearly polarized VHF signals from geostationary satellites such as Syncom and ATS has led to the development of the Stanford VHF polarimeter. This instrument measures the change in the Faraday rotation of VHF telemetry and beacon transmissions from these satellites and thus produces a continuous detailed record of ionospheric electron content over a fixed raypath. Installation of a number of these receivers at strategic locations allows observation of total electron content and irregularities such as traveling disturbances in spatial and temporal planes. The advantages of the geostationary satellite over the lower orbit types are important for this application because the fixed raypath permits the collection of accurate long-term data with little manual attention required.

In the area of deep-space research, the polarimeter is serving well. Measurements of the interplanetary electron number density by group-delay methods between deep-space probes (Pioneer, Mariner) and ground-based transmitters at Stanford University have extensively utilized polarimeter data to remove the substantial contribution of the ionosphere from the total measurement. In addition, as the precision of S-band ranging to spacecraft has increased, the need for accounting for the ionosphere on a routine basis has become apparent.

At least one commercial polarimeter, manufactured by Smyth Associates, has appeared on the market. It has greater flexibility than the instrument described in this report, but it is far more expensive; furthermore, the small size of the market makes it unlikely that such systems will be manufactured again.

Early polarimeters were simple because they were constructed from existing communications receivers and laboratory equipment. They tended to be bulky and, as a result, were not easy to transport to remote sites. The technique consisted of recording, on a strip chart, the detected output of a communications receiver that was connected, via an appropriate VHF converter, to an antenna rotating at 1 rpm. A reference signal, generated mechanically at the antenna, was also recorded. The chart-recorder speed had to be fast enough to observe the individual maximum and minimum signal amplitudes as the antenna rotated, so as to analyze the phase difference between signal minima and the reference. The compromise between sampling rate (antenna-rotation speed) and the amount of chart bulk produced was not good; efficiency of the data reduction was also poor.

To improve the earlier systems, the sampling rate was increased by rotating the antenna at high speed and by using a phase meter for signal and reference comparison.† Figure 3 is a simplified block diagram of this modified system. The phase-meter output is recorded on a strip chart at a speed between 1 to 6 in./hour, as compared to 30 to 60 in./hour,

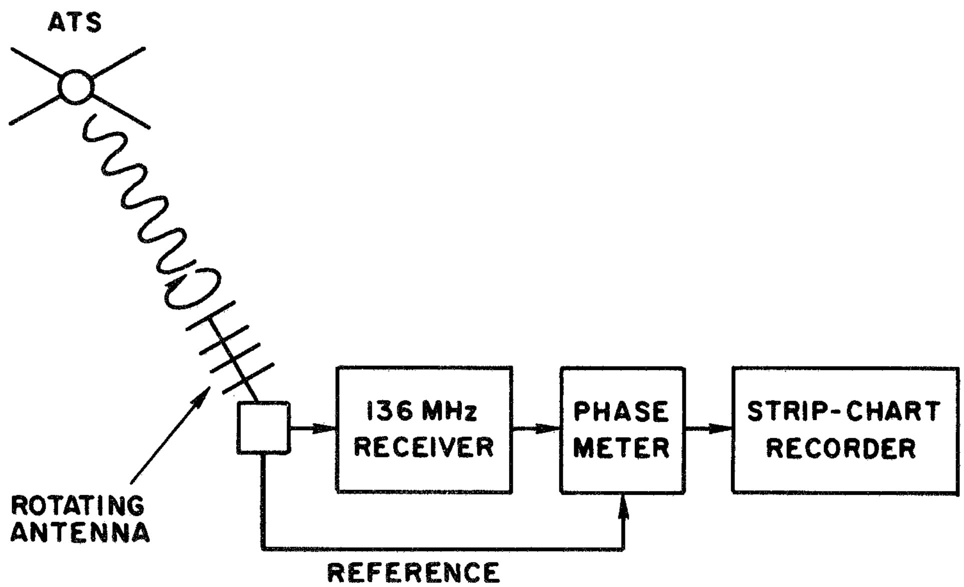


Fig. 3. SIMPLIFIED BLOCK DIAGRAM OF THE POLARIMETER.

for the original slow-rotation system. Antenna-rotation speed limitations are governed primarily by mechanical considerations; 87.5 rpm is a reasonable compromise between sample rate and system reliability. One excursion across the chart represents 180° of polarization angle change, making the data very easy to reduce manually, as shown in Fig. 4. Figure 5 is an example of an actual record. An additional advantage is that only a single-channel recorder is required because the reference does not need to be recorded separately.

---

† J. E. Titheridge, J. Atmos. Terrest. Phys., 28, 1966, pp. 1135-1150.

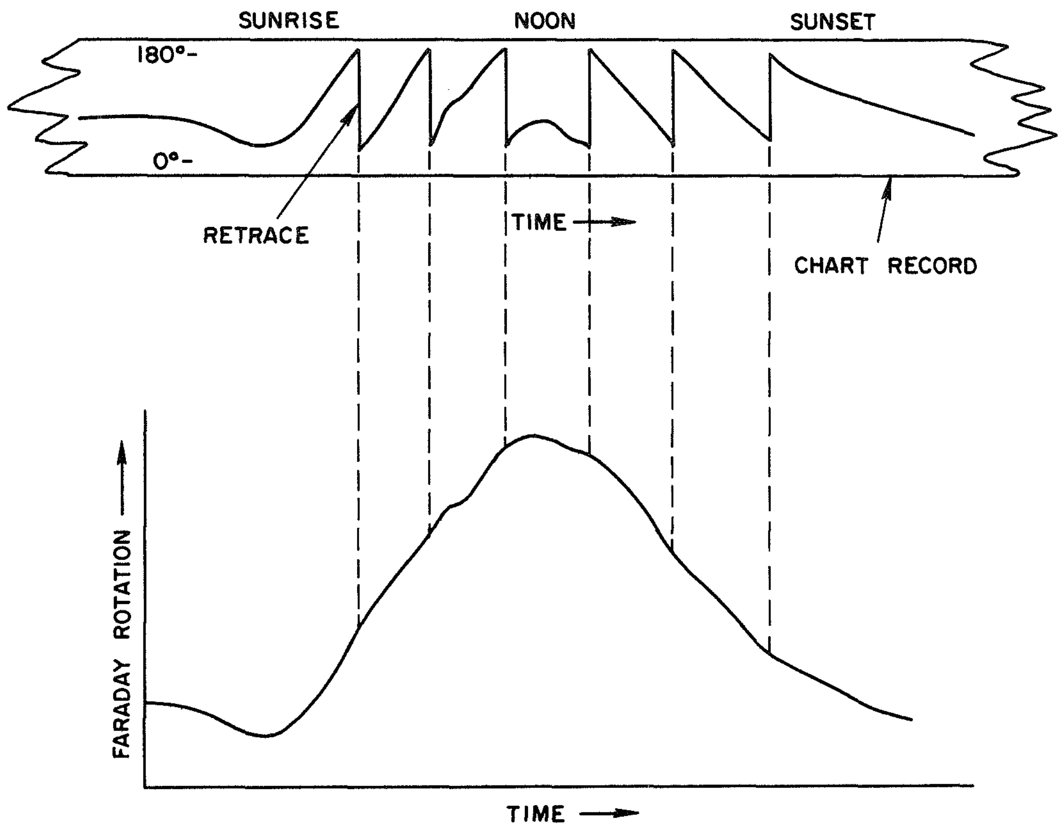


Fig. 4. CHART-RECORD DEFINITION.

The development of the Stanford equipment had three primary objectives.

(1) Low Cost: It is estimated that the complete system can be reproduced for less than $1500, including parts, materials, labor, university overhead, and recorder.

(2) Ease of Replication: The approach of an integrated receiver/phase meter on a printed-circuit board and an antenna constructed from common materials can be duplicated in the average laboratory or shop without special tools.

(3) Light Weight and Compactness: The complete system weighs less than 100 lb and breaks down for easy transportation in an automobile or a light airplane.

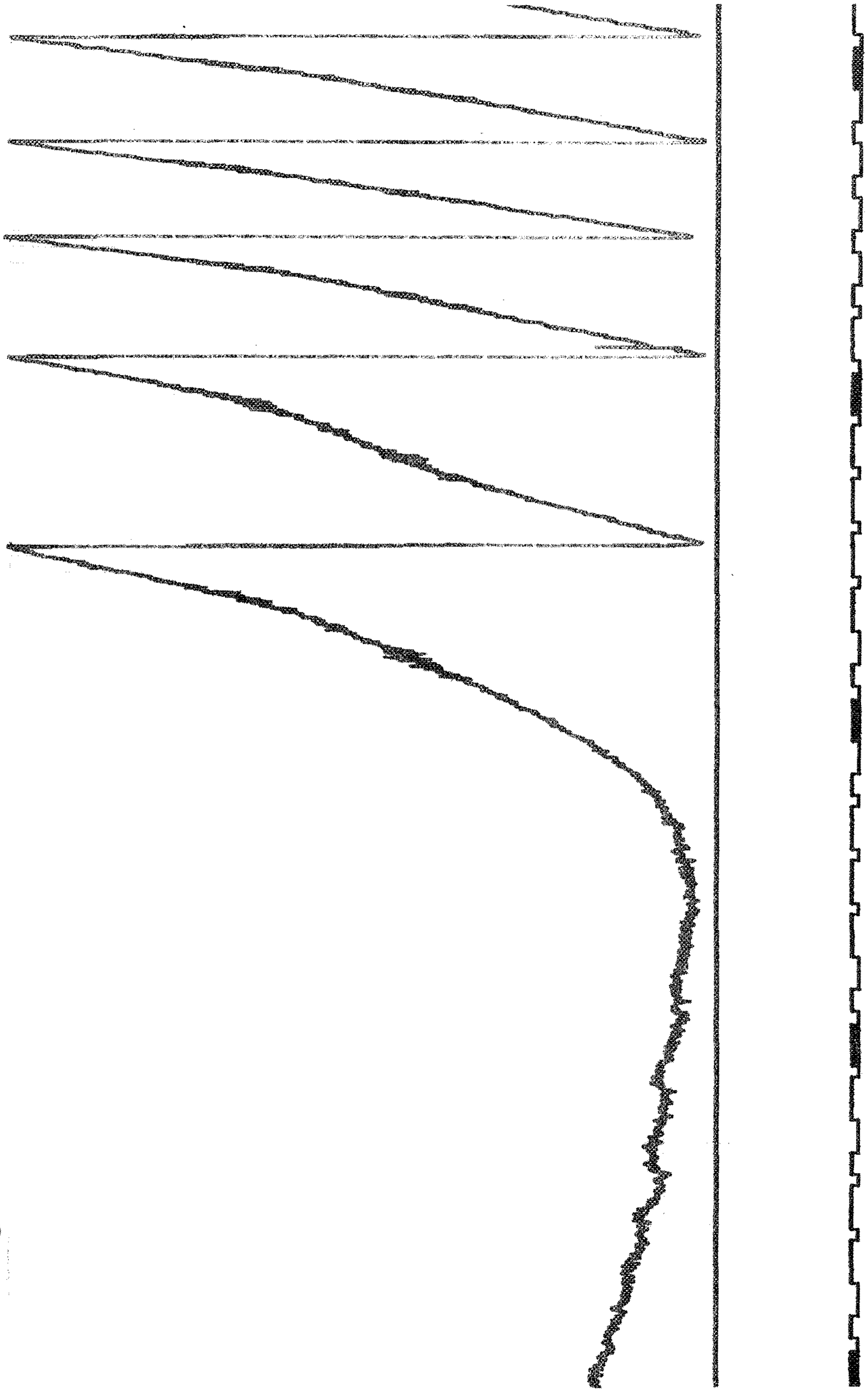


Fig 5

Fig. 5. SAMPLE RECORD.

Chapter III

SYSTEM DESCRIPTION

A. The Antenna

The antenna portion of the polarimeter samples the polarization angle of the incoming linearly polarized VHF transmission from a geostationary satellite. It is mechanically rotated at 87.5 rpm by an electric motor and suitable gear reduction (Fig. 6). When the plane containing the antenna elements is the same as that of the incoming signal, the antenna output is maximum; the output is minimum when the antenna is orthogonal to the signal. The effect is to amplitude modulate the signal with a low-frequency component which, because of the 180° ambiguity of the antenna, occurs at twice the rotation rate (approximately 2.91 Hz). The reference signal required for phase comparison is generated by magnetically closing a reed switch every 180° of antenna rotation.

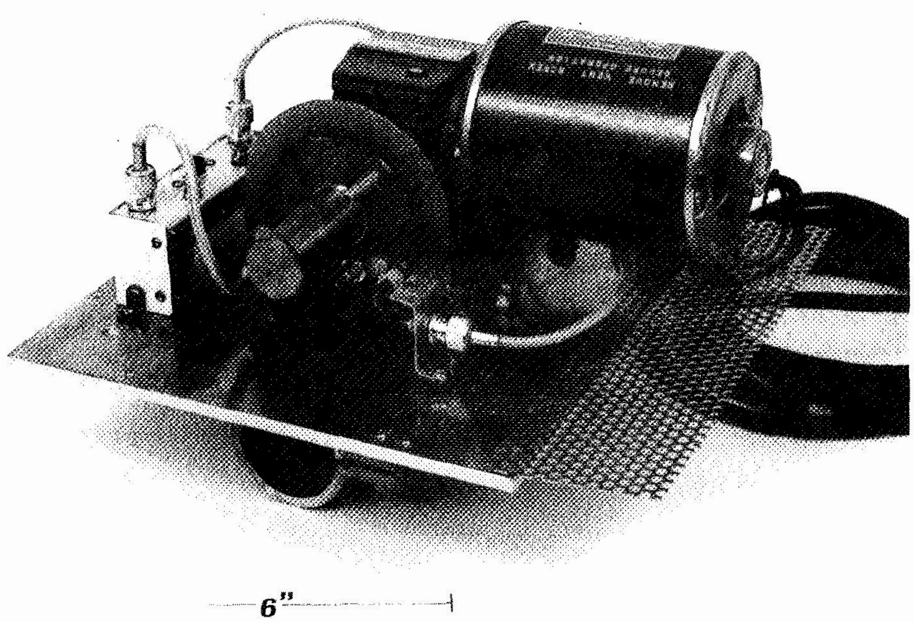


Fig. 6. ROTATOR-PLATFORM ASSEMBLY.

The antenna used in this system is a four-element Yagi-Uda type that afforded an adequate compromise between the signal-to-noise ratio and rotating mass. Some directivity is necessary to prevent reflection interference from nearby objects. As can be seen in Fig. 7, antenna construction of aluminum tubing and a quick-disconnect type of element-to-boom fitting allows easy assembly and compact transportation. To

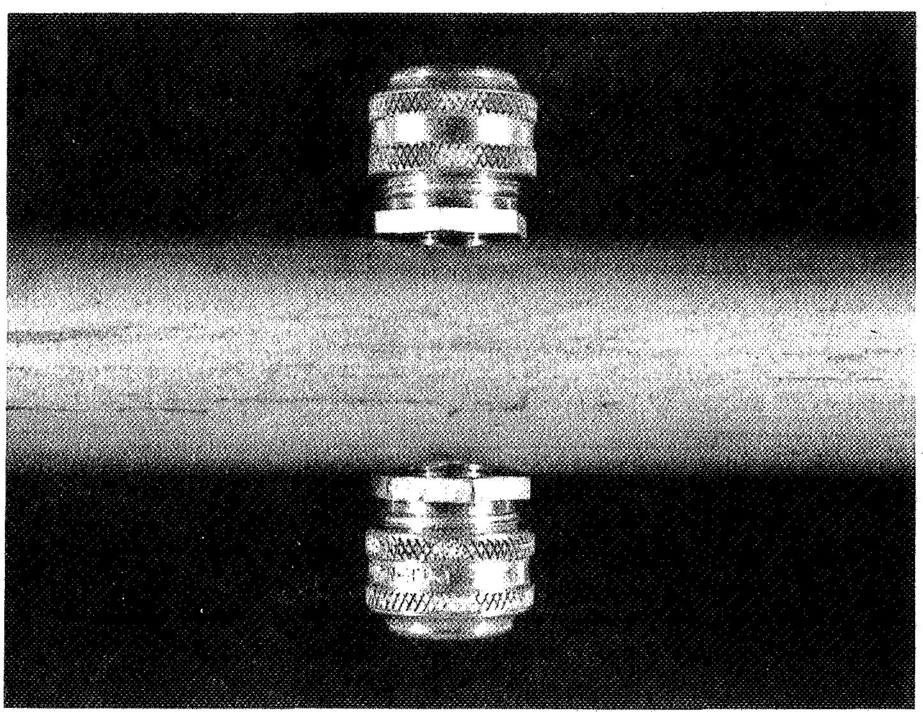


Fig. 7. ANTENNA-ELEMENT FITTINGS.

simplify antenna matching, element spacings and lengths were chosen to yield a feed impedance of close to 50 Ω. The feedline is a miniature 50 Ω coaxial cable (RG-174/U) connected to the antenna-driven element inside the boom to provide a weather seal. This feedline emerges from the boom a quarter wavelength behind the driven element (providing a sleeve-decoupling balun), and its outer conductor is connected to the boom at this point to prevent currents from flowing on the outside of the cable.

The rotating antenna is connected to a preamplifier, via a single-turn series-resonant rotary joint. When properly spaced and tuned, this joint (Fig. 8) yields less than 0.1 dB of loss. Once tuned, spacing is relatively uncritical, with less than 0.2 dB of loss resulting for spacings between 0.1 and 0.2 in.

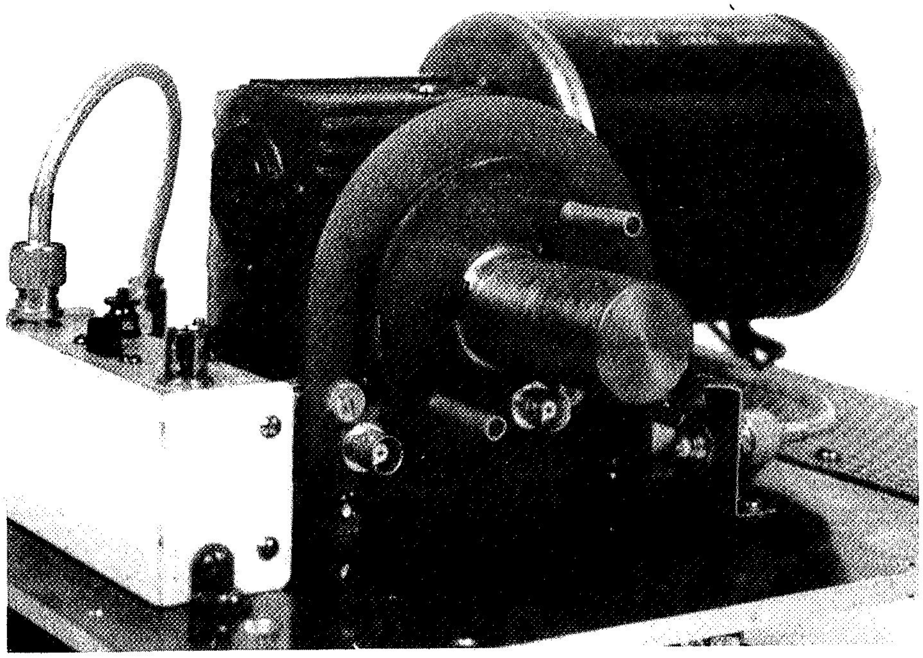


Fig. 8. ROTARY JOINT.

Each half of the joint is comprised of a printed-circuit inductive loop on 1/8 in. G-10 glass laminate, which also carries the variable capacitor and BNC connector. The conductors are gold plated to minimize corrosion. The rotating half of this joint is mounted on a flange of the brass antenna-to-gearbox coupling; the position of this coupling on the gearbox shaft determines the joint spacing. The fixed half of the joint is fastened to the motor plate with an aluminum angle bracket.

Two brass tubes housing slim permanent magnets are mounted near the circumference of the rotating half of the rotary joint and are spaced 180° apart. These magnets actuate a reed switch mounted on a nearby bracket to furnish rotation-reference pulses.

The rotary-joint output goes directly to a low-cost high-performance preamplifier. This device uses dual-gate FETs in a two-stage circuit, yielding a 2.5 dB noise figure with 35 dB gain to overcome feedline losses and to set the system-noise figure. Direct-current power is sent up the signal feedline from the receiver/phase meter, thus eliminating the need for a separate power supply. Rotation power is obtained from an integral motor gearbox, using a 1/12 HP motor and a 20:1 worm gear reduction. The gearbox is furnished with adjustable mountings to allow rotary-joint centering.

A 1/4 in. aluminum plate ensures a stable platform for all components and is covered by an aluminum box for weather protection; ventilation holes in both the mounting plate and the box provide motor cooling. A tubular arm extending from the rear of the plate allows easy antenna positioning. An all-aluminum tripod stand, constructed of tubing and angle, mounts the motor plate approximately 7 ft above the ground. The mounting head (Fig. 9) is bolted to the bottom of the motor plate to permit azimuth and elevation adjustment.

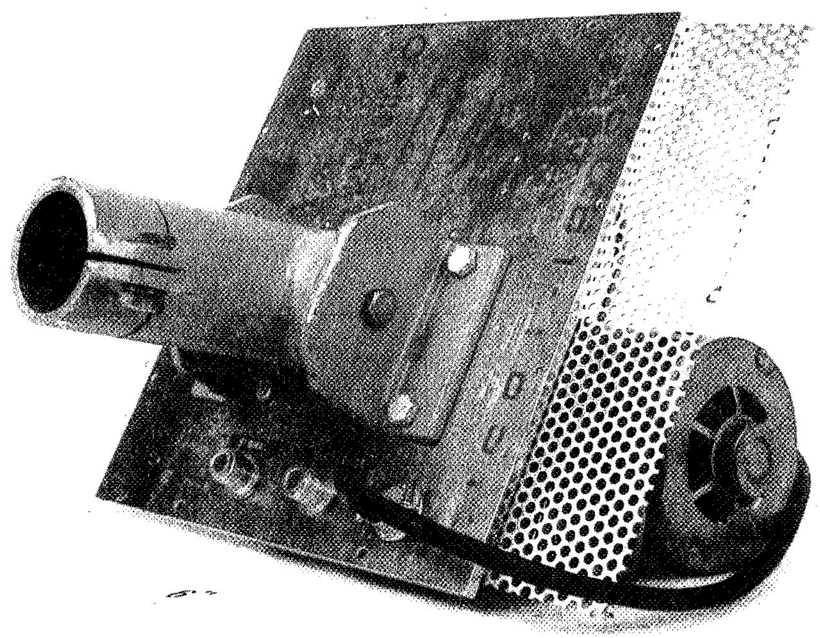


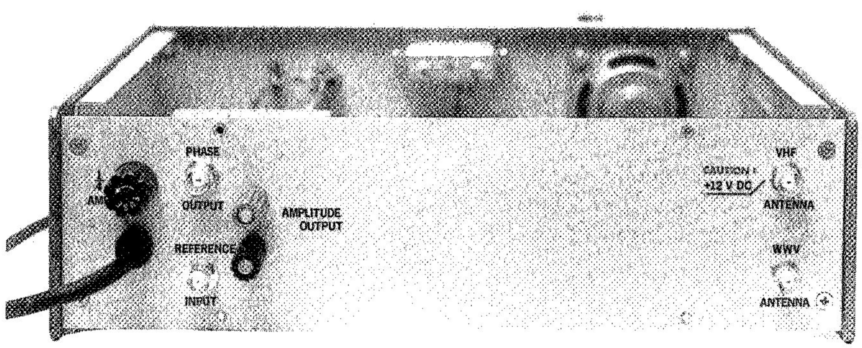
Fig. 9. ADJUSTABLE MOUNTING HEAD.

B. Receiver/Phase Meter

This compact unit (Fig. 10) consists of a crystal-controlled dual-conversion receiver and a digital phase meter that compares the sampled VHF signal and reference pulses from the antenna system. It provides an analog output, proportional to polarization angle, that is suitable for strip-chart recording. Provisions also are made for the reception of standard time signals on 10 MHz for chart-timing reference. For users interested in signal-amplitude data, a rear-panel output provides a connection to a chart recorder. A front-panel meter indicates average signal strength. By using a single printed-circuit board and modular RF assemblies, ease of assembly and duplication is guaranteed. Power supplies are self-contained and have sufficient reserve capacity for accessories.

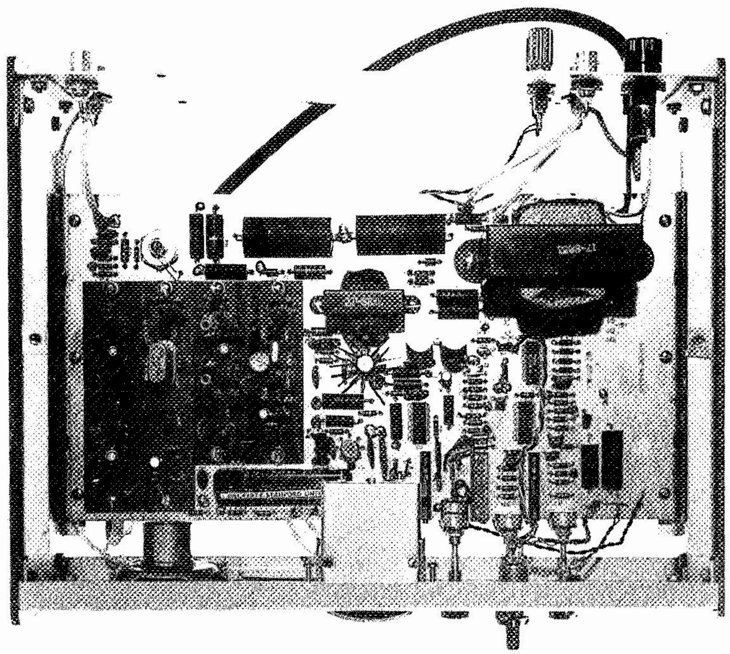
The antenna-mounted preamplifier, manufactured by Vanguard Electronics Laboratories, yields a 2.5 dB noise figure for good receiver sensitivity and sufficient gain (35 dB) to overcome feedline losses, which permits the antenna to be installed 1000 ft from the receiver. Good overload and cross-modulation characteristics are attained by use of dual-gate MOSFETs in both stages. Diodes are utilized at the input to protect the first stage from nearby transmitters; these diodes, plus selectivity obtained in the antenna and in the tuned rotary joint, ensure safe operation in close proximity to a 300 kW 50 MHz transmitter. By the addition of two components, the commercial preamplifier is modified to accept its operating dc power from the feedline.

a. Front view

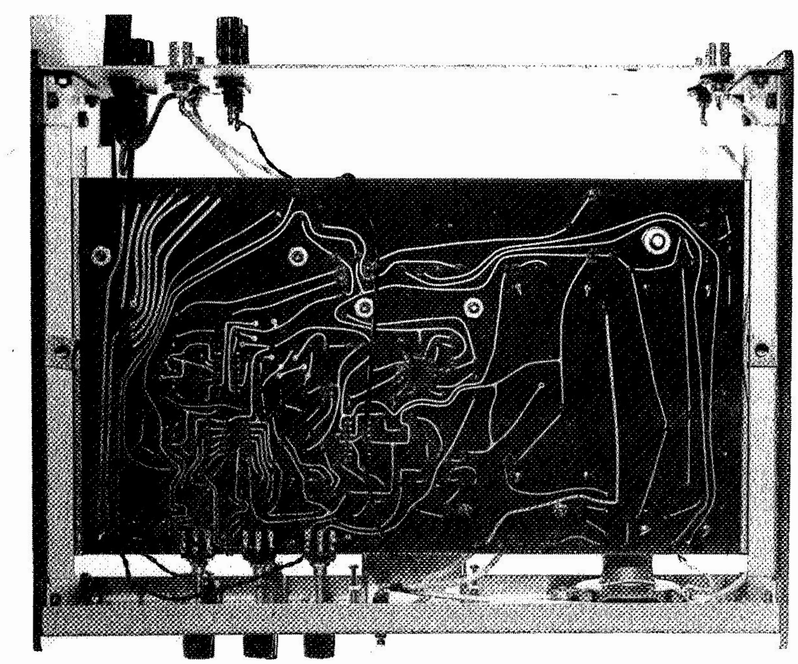


b. Rear view

Fig. 10. RECEIVER/PHASE-METER ANGLES.



c. Top view



d. Bottom view

Fig. 10. CONTINUED.

C. System Block Diagram (Fig. 11)

The 137.35 MHz ATS satellite signal received by the rotating antenna is passed via a tuned rotary transformer to a two-stage preamplifier. The preamplifier output is connected by coaxial cable to the receiver/phase meter, where two additional stages of VHF gain are provided to allow flexibility in the relative locations of the antenna and receiver. The excess gain in a given system is dissipated in resistive pads to prevent the overload of following stages.

A crystal-controlled conversion oscillator converts the VHF signal to a 10 MHz first IF. The choice of this intermediate frequency, plus a large number (10) of tuned circuits preceding conversion, affords excellent image rejection; this IF also allows the remaining portion of the receiver to be used for WWV reception, as selected by a front-panel switch. One stage of 10 MHz gain precedes the second mixer, where conversion to the 455 kHz second IF takes place; the oscillator for this conversion is also crystal controlled. The second-mixer output is coupled to a mechanical filter that sets the receiver selectivity at 2.1 kHz. The following stage is a single integrated circuit that provides IF gain, AGC, detection, and audio amplification.

The AGC voltage is buffered in a dc amplifier to drive the front-panel meter and rear-panel output for signal-strength indication. Audio-power amplification is obtained in an integrated circuit, delivering 1 W to the speaker.

The receiver audio output consists of noise, modulation on the satellite telemetry signal, and a 2.91 Hz component which is the antenna sampling rate. This composite signal is passed through a lowpass filter and amplifier to remove most components above 5 Hz and to provide sufficient drive to the active filter. The high-Q active filter delivers the large-amplitude clean-waveform 2.91 Hz signal necessary for processing in the digital phase meter. The FET buffer, following the active filter, prevents loading and degradation of the Q filter. The 2.91 Hz signal is amplified and squared in three stages of a DTL hex inverter integrated circuit; the pulses from the antenna-reference switch also are processed in one of the inverters.

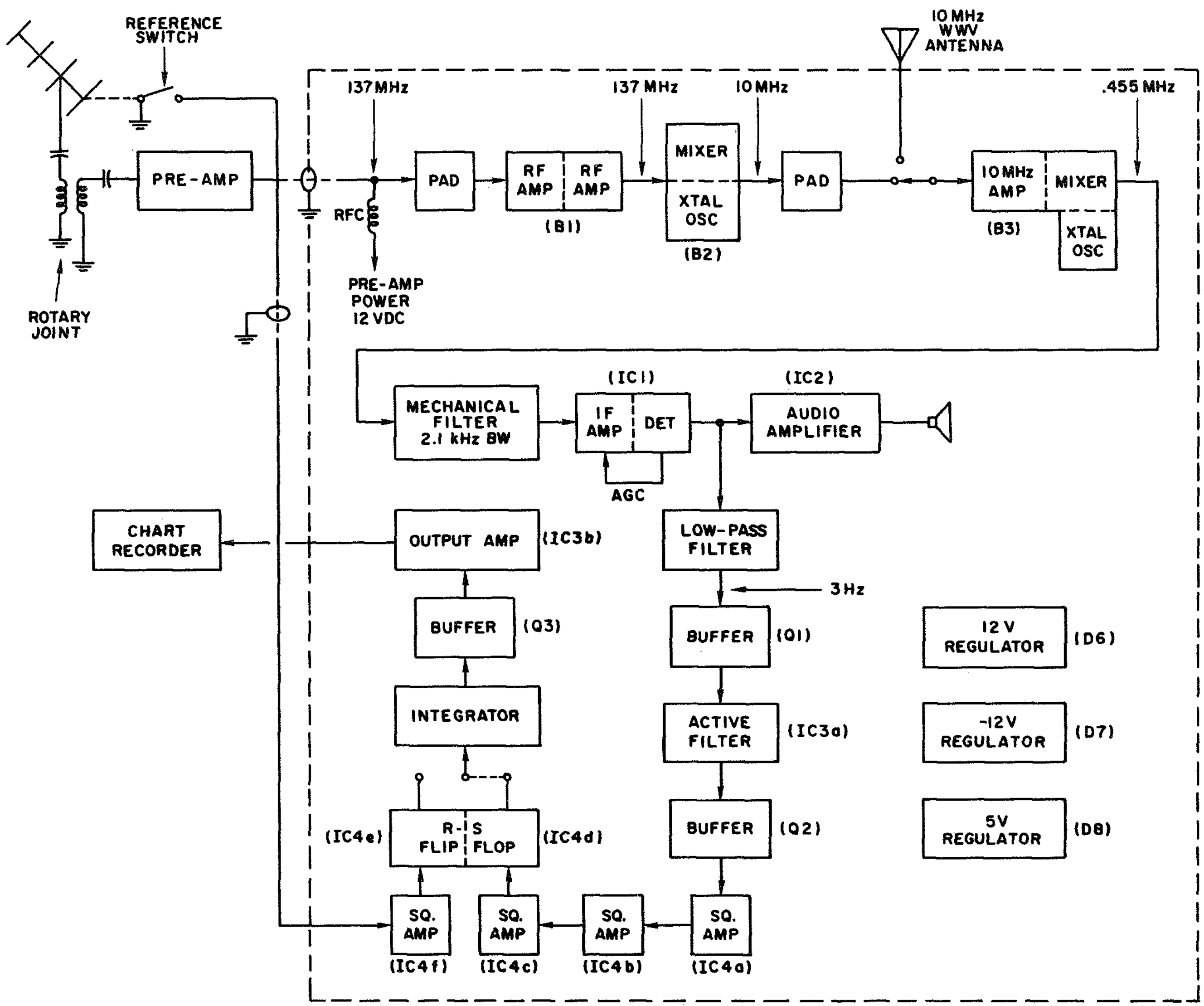


Fig. 11. BLOCK DIAGRAM OF THE STANFORD VHF POLARIMETER.

The remaining two inverters of the package are cross-connected to form an R-S flip-flop. Because the squared signal and reference pulses are differentiated and applied to opposite sides of this flip-flop, its output is a rectangular pulse whose width is proportional to the phase difference between the signal and reference. To obtain the analog of this information, a simple RC integrator with two selectable time constants is employed. The FET buffer follows this integrator and drives the output dc amplifier which provides adjustable gain and bias and a low-output impedance recorder drive.

D. Receiver-Circuit Description (Fig. 12)

The preamplifier receives its dc power through a lowpass filter consisting of capacitor C2 and choke RFC. To reduce the preamplifier gain, R58 reduces the 12 V receiver supply voltage to approximately 9 V. C1 provides dc blocking and signal coupling to a resistive T-pad made up of R47, R48, and R49. This pad prevents overload of the RF stage on board B1 and is changed to compensate for differences in preamp gain and/or feedline lengths; the values shown are suitable for a 100 ft feedline.

The RF amplifier board (B1) and mixer-oscillator board (B2) were obtained from a Vanguard Electronics Laboratories model 407 converter, and were removed from the converter package and mounted on the mother PC board. B1 (Fig. 13a) consists of two dual-gate FET RF stages and four tuned circuits for good image rejection and is identical to the preamplifier. R57 reduces its operating voltage to approximately 9 V.

The oscillator portion of B2 (Fig. 13b) is a bipolar-transistor third-overtone crystal oscillator, with its collector circuit tuned to 42.450 MHz by L1. The third harmonic (127.350 MHz) of the crystal frequency is selected by L2 and C2 and is passed to gate 2 of the dual-gate FET mixer, where the signal frequency of 137.350 MHz is converted to 10 MHz. This type of mixer yields good conversion gain and low spurious generation. The 10 MHz first IF is attenuated in R1, R2, and R3 to provide the correct signal level for the second converter. Front-panel switch S3 selects either the converted VHF signal or an external WWV antenna for the second converter input.

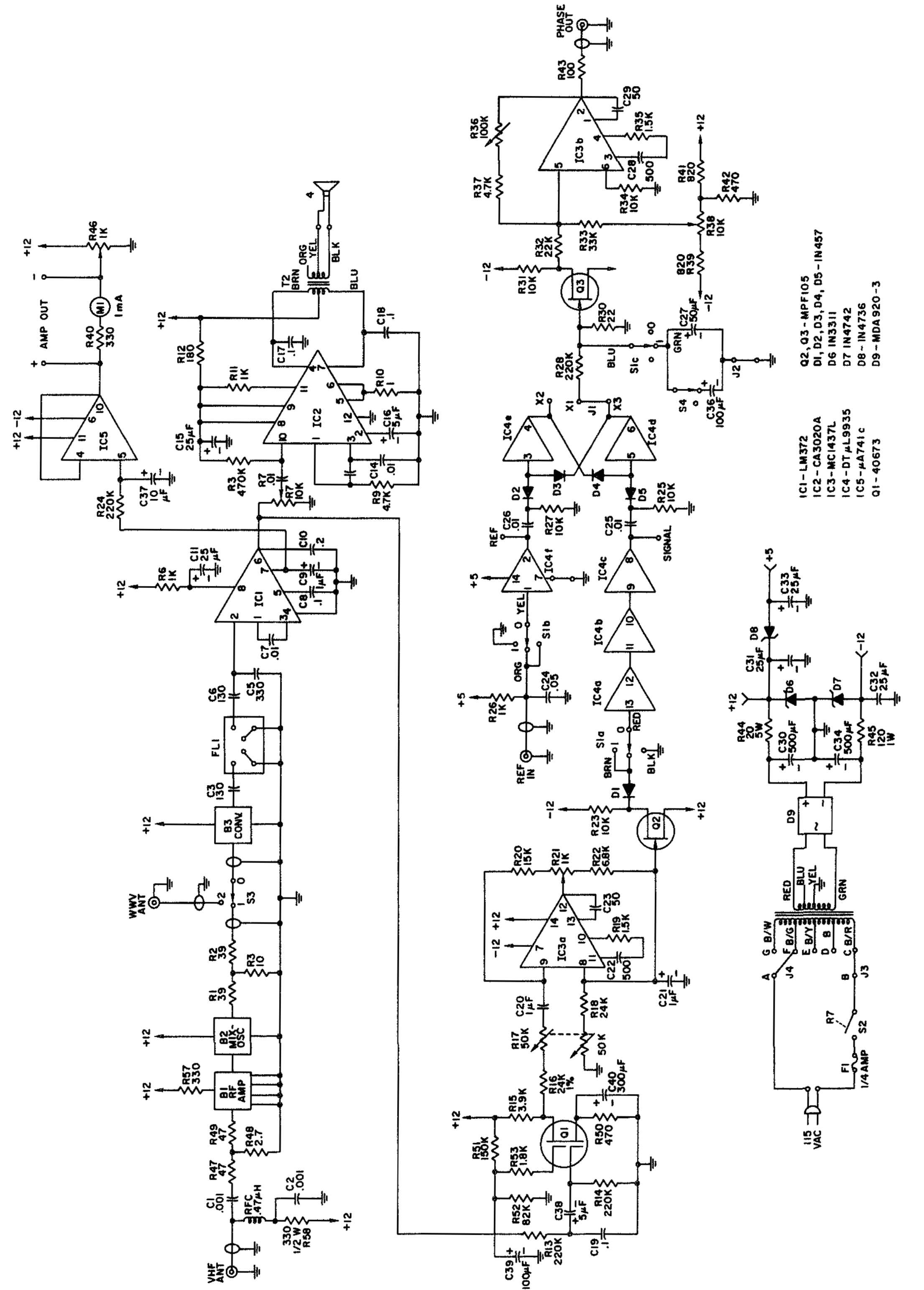
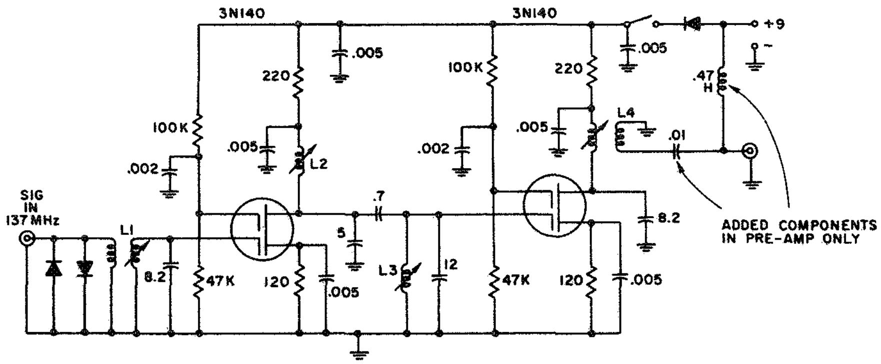
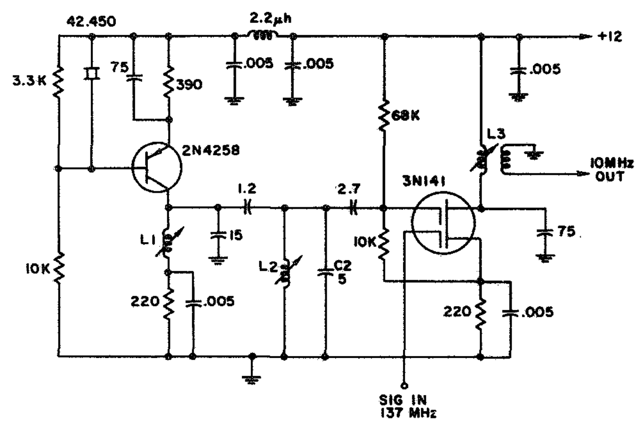


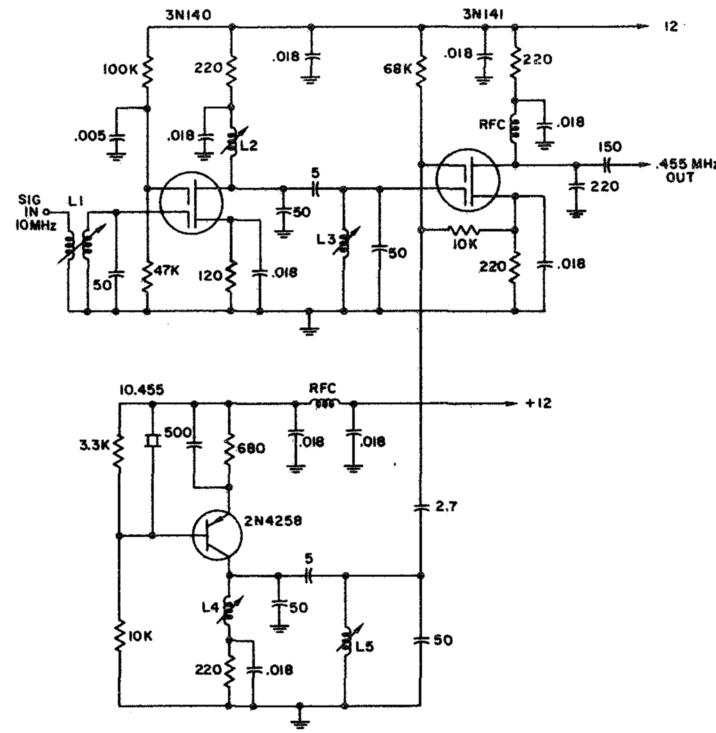
Fig. 12. SCHEMATIC OF THE RECEIVER/PHASE METER.



a. Vanguard preamplifier and model 407 RF amplifier B1



b. Model 407 converter mixer-oscillator (B2)



c. Model 306 converter (B3)

Fig. 13. SCHEMATIC DIAGRAMS OF THE RF MODULES.

Board B3 (Fig. 13c) is a Vanguard model 306 converter, also removed from its case and mounted on the mother board. This unit consists of one stage of 10 MHz gain, a crystal oscillator at 10.455 MHz, and a dual-gate FET mixer whose output is at 455 kHz; both oscillator and mixer are similar to those of the first converter. The 455 kHz second IF is coupled to a Collins mechanical filter that has a 2.1 kHz -3 dB bandwidth. Capacitors C3 and C6 series resonate the filter input and output, respectively, and C5 supplies HF bypassing at the second IF amplifier input.

Integrated circuit IC1 (a National LM372) is used for IF gain, AGC, detection, and audio preamplification; this circuit has performed well in this application. C7 is applied for interstage coupling while C8 bypasses at 455 kHz. The AGC line appears at pin 7, and the time constant is set by C9. C10 is part of the detector-output filter and is made large enough to limit the high-frequency audio response. Vcc decoupling is provided by R6 and C11; the detected output is connected to both the phase-meter input and volume control R7.

Audio amplification occurs in IC2 (RCA CA3020A) which has 70 dB gain and will deliver 1 W to the speaker; however, for stable operation, its high-frequency capability makes it somewhat critical to proper bypassing. Capacitors C14, C15, C16, C17, C18 complete the necessary bypassing. C12 couples the audio from the volume control to the emitter-follower input and limits the low-frequency response. R8 and R9 are the input emitter-follower bias and emitter resistors, respectively. The output transistors are operated in class B, and R10 provides degeneration for stability and lower distortion. The output transformer T2 matches the 200 Ω collector-output impedance to the 4 Ω speaker.

The AGC voltage developed in IC1 is utilized for signal-level indication by lowpass filtering in R24 and C37 and buffering in a voltage-follower connected operational amplifier IC5 (a 741C). The low-impedance output of IC5 is connected to the front-panel meter, via the meter-range resistor R40. R46 allows adjustment of the meter zero position to compensate for the quiescent voltage on the AGC line. Floating rear-panel outputs are employed for remote metering or recording.

The receiver detector output is coupled to gate 1 of Q1, via lowpass filter R13, and C19, and coupling capacitor C38. At this point, ac coupling is necessary because of the dc bias at the detector output. Q1 (a dual-gate FET) is used as a high-input impedance voltage amplifier to supply sufficient drive to the active filter IC3a. R51, R52, R53, and C39 set the gate-2 bias, and R14 is the gate-1 dc return. Source resistor R50 (bypassed by C40) and drain load R15 set the stage-operating point. The active filter is a multiple feedback loop type, using 1/2 of an IC dual-operational amplifier as the active element. This type of filter can provide high Q (100) and high gain (40 dB) with an ease of tune-up not found with the "Twin T" type. Center frequency and Q adjustment are essentially independent and are obtained by only two controls. R16, R17, R18, C20, and C21 are the center-frequency determining elements; R20, R21, and R22 set the ratio of positive-to-negative feedback and thus determine Q and gain. R19, C22, and C23 furnish frequency and phase compensation to the operational amplifier.

To prevent loading of the filter, a high-input impedance FET source follower Q2 is employed to buffer the output. D1 couples the output of Q2 to the input of IC4a (a DTL HEX inverter), via mode switch S1a. IC4 is a six-inverter package that accomplishes all the digital processing. Sections a, b, and c are used to square the active-filter sine-wave output. The input of section f normally is biased on by R26 but, when the antenna-reference switch closes, this input goes to ground, resulting in a pulse output. C24 provides noise filtering for the reference line. The reference pulse from inverter f and the signal pulse from inverter c are differentiated in RC networks C26 to R27 and C25 to R25, respectively. The negative-going narrow pulses trigger alternate sides of an R-S flip-flop formed by the cross-connected inverter sections d and e.

Diodes D2, D3, D4, and D5 give the necessary OR function at each inverter input. The flip-flop output is a rectangular pulse whose pulsewidth represents the time difference between the arrival of differentiated reference and signal pulses. To obtain the desired output sense, either side of the flip-flop output can be selected by jumper J1. Conversion of this pulsewidth information to an analog signal suitable for strip-chart recording is accomplished in a simple RC integrator consisting of R28 and C27; under noisy circumstances, S4 selects an additional capacitor C36 for an increased time constant.

To prevent loading of the integrator, the FET source follower Q2 precedes the output amplifier. The output stage IC3b is an inverting operational amplifier with adjustable gain and offset and a low-output impedance for driving a variety of chart recorders. Adjustable-output offset is obtained from divider network R33, R38, R39, R41, and R42; adjustment of R36 in the feedback loop controls the amplifier gain. R43 protects the output stage from inadvertent short circuit, and compensation components R35, C28, and C29 stabilize this stage. To calibrate the output, the flip-flop must be set in each of its two stable states; S1, a three-pole three-position panel-mounted switch, accomplishes this by grounding the input of IC4a or IC4f. This provides the output end points, and calibration is made by adjustments of level control R36 and balance control R38. To allow rapid calibration without the integrator time constant in effect, S1c opens the connection to the integration capacitors in the two calibrate positions.

Chapter IV

CONSTRUCTION

A. Antenna System

The following photographs and drawings illustrate in detail the construction of the antenna system. The metal work consists of

(1) antenna elements
 all elements: .25 in. OD .049 wall-aluminum tubing
 reflector: 42.5 in.
 two driven elements: 20.25 in.
 first director: 38 in.
 second director: 37 in.

(2) antenna boom (Fig. 14)

(3) drip ring (Fig. 15)

(4) shaft-boom coupling (Fig. 16)

(5) rotary-joint (Fig. 17) and reference-switch (Fig. 18) brackets

(6) rotator plate (Fig. 19)

(7) mounting head (Fig. 20)

(8) tripod mast (Figs. 21,22), legs and braces (Fig. 23), head angle (Fig. 24), and foot (Fig. 25)

(9) rotator cover (Fig. 26)

The rotary-joint layout (Fig. 27) is full size and suitable for direct photography for printed-circuit reproduction. Drilling information is presented in Fig. 28.[†]

1. Antenna Assembly

Antenna assembly begins by mounting the element to boom fittings on the boom, as detailed in Fig. 29; all the parasitic elements are similarly mounted. The split driven-element mounting and feed assembly is illustrated in Fig. 30. The drip ring is slid on the boom and is positioned between the reflector and hole A; the RG-174/U feedline emerges from the boom at this hole. At this point, the outer jacket is stripped off for 1/2 in., and the shield is secured to the boom by a grounding clip. RTV silicone rubber is used for a weather seal. A BNC connector

[†]For convenience, Figs. 14-44 will be found at the end of this chapter.

now is fastened on the free end of the feedline, which will mate with the rotating half of the rotary joint during final assembly.

Antenna elements are mounted by sliding one of the rubber-mounting bushings on the element to the approximate center. (A little talc will help.) The element is inserted through the boom fittings, and the other rubber bushings are installed. Before final tightening, the washers and threaded caps are installed with the element being centered about the boom. A snap plug is fitted with RTV to the director end of the boom to complete the antenna assembly.

2. Rotary Joint

Assembly of the rotary joint (Figs. 31, 32, and 33) consists of installing a BNC panel connector and trimmer capacitor on each half. The capacitor is a friction fit in its mounting hole and is oriented so that one lead can be bent over and soldered directly to the end of the printed-circuit inductor. A short length of wire connects the center of the BNC to the other side of the capacitor. The rotating half of the joint is secured to the shaft-to-boom coupling, using No. 2 hardware with the printed-circuit side toward the shaft end of the coupling.

The No. 4 threaded spacers are partially drilled to accept the reference-switch actuating magnets as a push fit; these magnets are sealed in place with RTV. The spacers are secured to the rotating half of the joint with No. 4 hardware.

3. Mounting-Plate Assembly

The 1/4 in. - 20 × 1-1/2 in. gearbox mounting bolts are installed in holes A of the mounting plate; these bolts are inserted from the bottom and the nuts and lockwashers are secured. An additional nut is then threaded on each bolt, leaving approximately 3/8 in. of bolt thread exposed between the two nuts. The gearbox is placed on the studs and also is secured with nuts and lockwashers. These nuts must not be tightened at this time because the two nuts, above and below the gearbox mounting ears, will be used to adjust the final position of the gearbox for rotary-joint alignment. The fixed rotary-joint half and its bracket are fastened by No. 6 hardware to the mounting plate at holes B. The shaft-to-boom coupling is secured on the gearbox shaft, and the rotary-joint halves are positioned in close proximity.

The gearbox mounting nuts are now adjusted so that the rotary-joint halves are parallel to and concentric with each other. The reference-switch assembly is mounted to the plate with No. 6 hardware at holes C. The switch is so positioned that, on rotation, the magnets will just clear. The preamplifier is fastened to the plate at holes D, with its input connector toward the front of the plate. The motor relay is mounted at holes E and type "N" feedthrough connectors at holes F.

The mounting head tee is assembled to the mounting angles with a 3/8 × 4-1/2 in. bolt. The angles are secured to the bottom of the mounting plate with 5/16 in. hardware at holes G, orienting the tee pinch-bolt ears toward the rear of the plate. The tubular-positioning arm is fastened to the bottom of the plate at holes H, using 5/16 in. hardware with the long portion extending from the rear. A three-wire line cord is installed through the cable clamp, and this and the motor leads are wired to the relay (Fig. 34); this will result in counter-clockwise rotation of the antenna, as viewed from the rear. Cables of RG-58a/U are assembled and installed between the rotary-joint output and the preamplifier input, between the preamplifier output and plate feedthrough connector and between the reference switch and the other plate feedthrough connector. The ventilation screen is fastened to the top of the mounting plate with No. 6 hardware. The antenna boom is slid on the shaft-to-boom coupling and secured with a hose clamp.

4. Tripod Assembly

The assembly of the tripod support stand is straightforward and is best explained by Fig. 35.

B. Receiver/Phase Meter

A single large printed-circuit board to carry all major components greatly simplifies the construction of this unit. Metal work is minimized by utilizing a ready-made cabinet. Components were selected because of their availability; most of them are stocked in one of the large mail-order supply houses.

1. Cabinet Preparation

Front, rear, and side panel layouts are illustrated in Figs. 36, 37, and 38. Panel lettering can be seen in Fig. 10 and should be applied before the cabinet is assembled; dry-transfer decals are adequate if suitably coated after application. Figure 39 details the mounting brackets of the PC board, and they should be fastened to the inner side panels (Fig. 40) before cabinet assembly is completed. Panel-mounted components now can be assembled but should not be tightened until the PC board is installed.

2. RF Module Preparation

The PC boards are removed from the cases of the Vanguard models 407 and 306 converters, and the grounding solder lugs are clipped off. At each point where an underboard hook-up wire was originally connected, a 4 in. length of No. 22 bare wire is soldered; these wires will make the connections to the mother board.

3. Printed-Circuit Board

The layout of the printed-circuit board (Fig. 41) is presented in Fig. 42; it is half size and suitable for direct photography and enlargement for board reproduction by conventional means. Because of board size and component weight, 1/8 in. G-10 board material is necessary.

A solder coating should be applied to both sides of the board for solderability and corrosion protection. Drilling information is supplied in Fig. 43.

Figures 41 and 44 and the parts list provide sufficient information for component installation. All ground connections are made to the top side of the board, some with through pins. Mounting of the RF modules is accomplished by installing 1/4 in. No. 4 threaded spacers on the top of the mother board, using No. 4 $\times$ 1/4 in. hardware at the eight-module mounting holes. The long wire leads extending from each RF module are inserted into the appropriate holes of the PC board, and the module is gently pushed down against the mounting spacers and secured with No. 4 $\times$ 3/16 in. screws. No. 16 bare-wire ground leads from the ground eyelets on module B1 are soldered to the top of the mother board.

4. Final Assembly

The completed PC board is installed in the assembled cabinet on the angle mounting brackets, with the control shafts extending through the front-panel bushings. The wiring between the board and the panel-mounted components now can be completed.

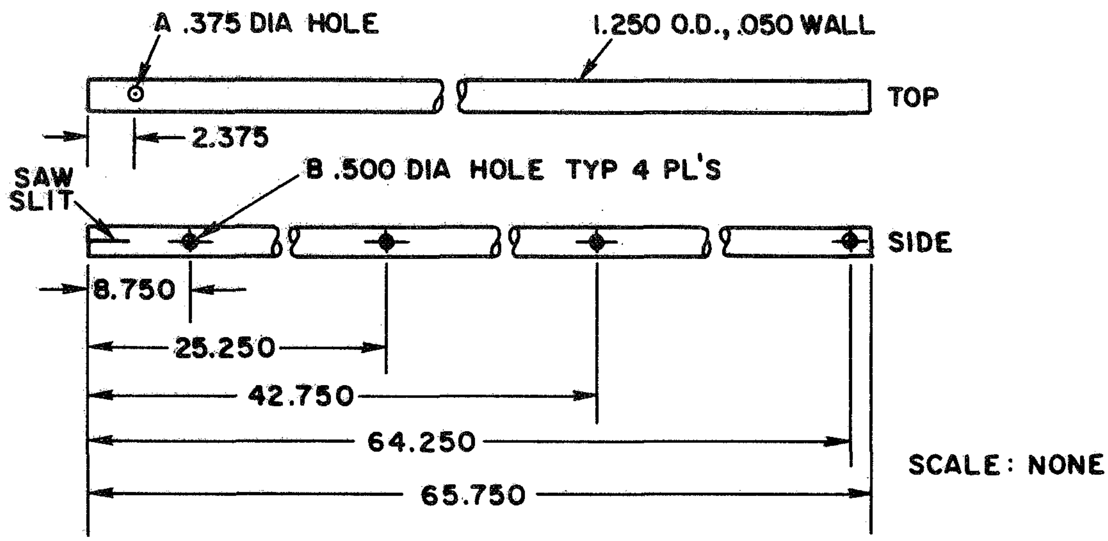


Fig. 14. ANTENNA BOOM.

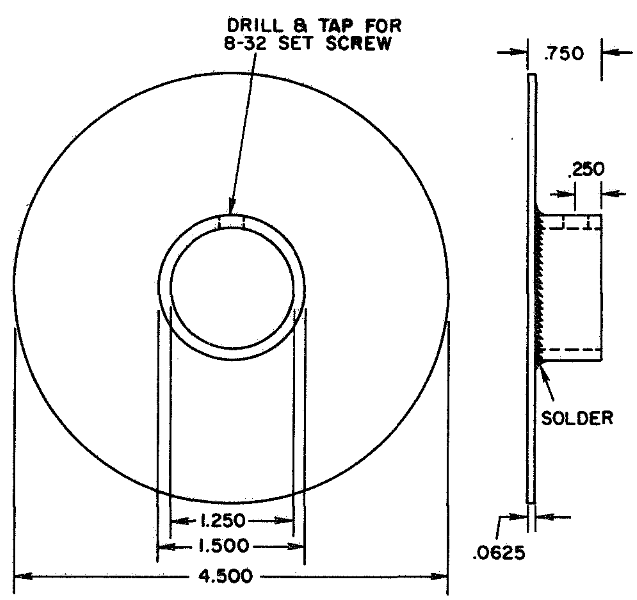


Fig. 15. ANTENNA DRIP RING.

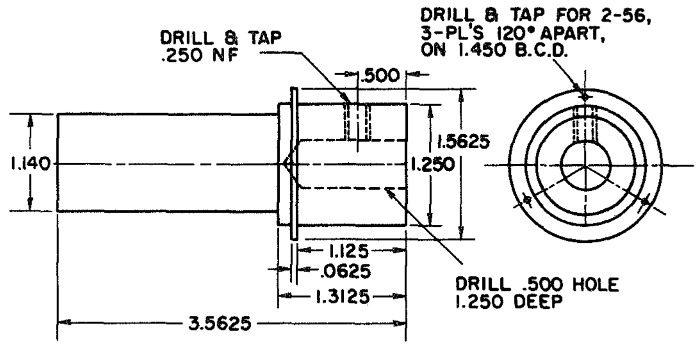


Fig. 16. SHAFT/BOOM COUPLING.

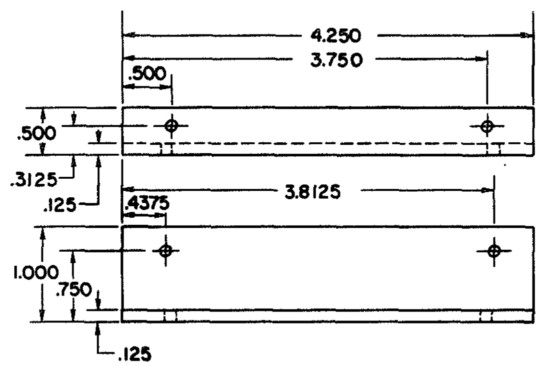


Fig. 17. ROTARY-JOINT BRACKET.

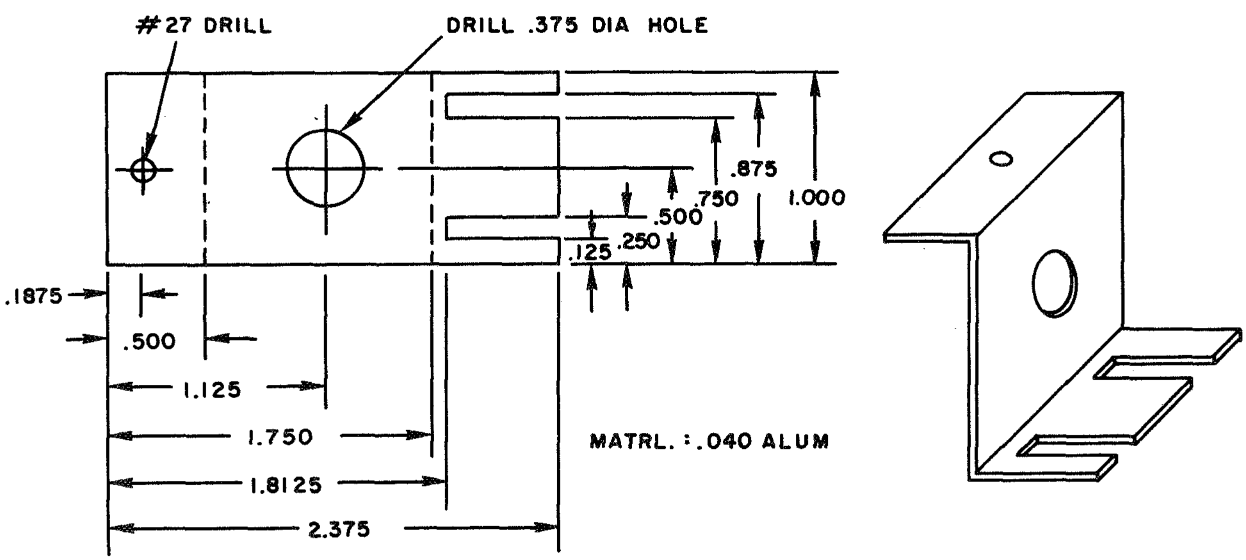
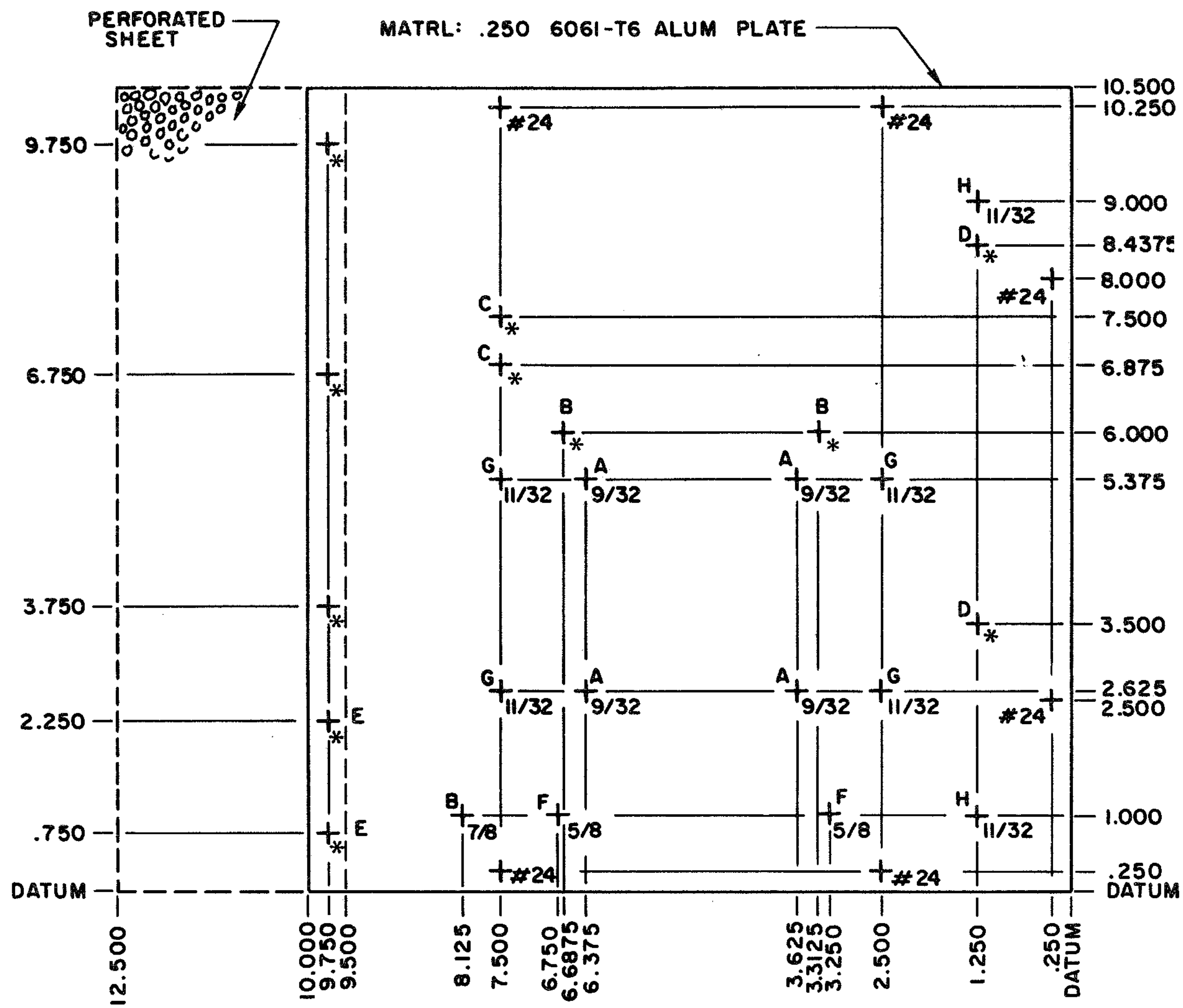


Fig. 18. REFERENCE-SWITCH BRACKET.



* DRILL AND TAP FOR 6-32

Fig. 19. ROTATOR PLATE.

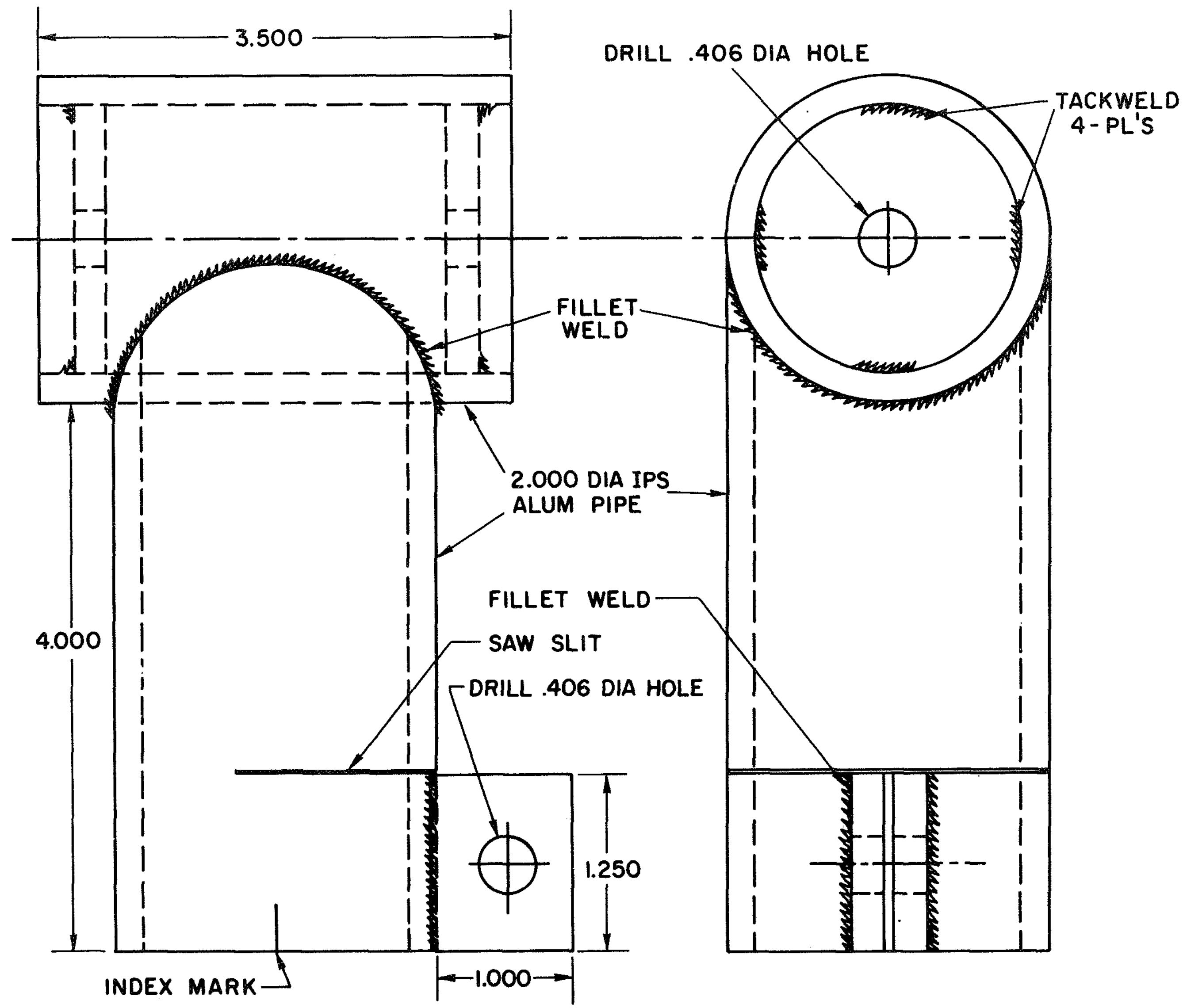


Fig. 20. MOUNTING HEAD.

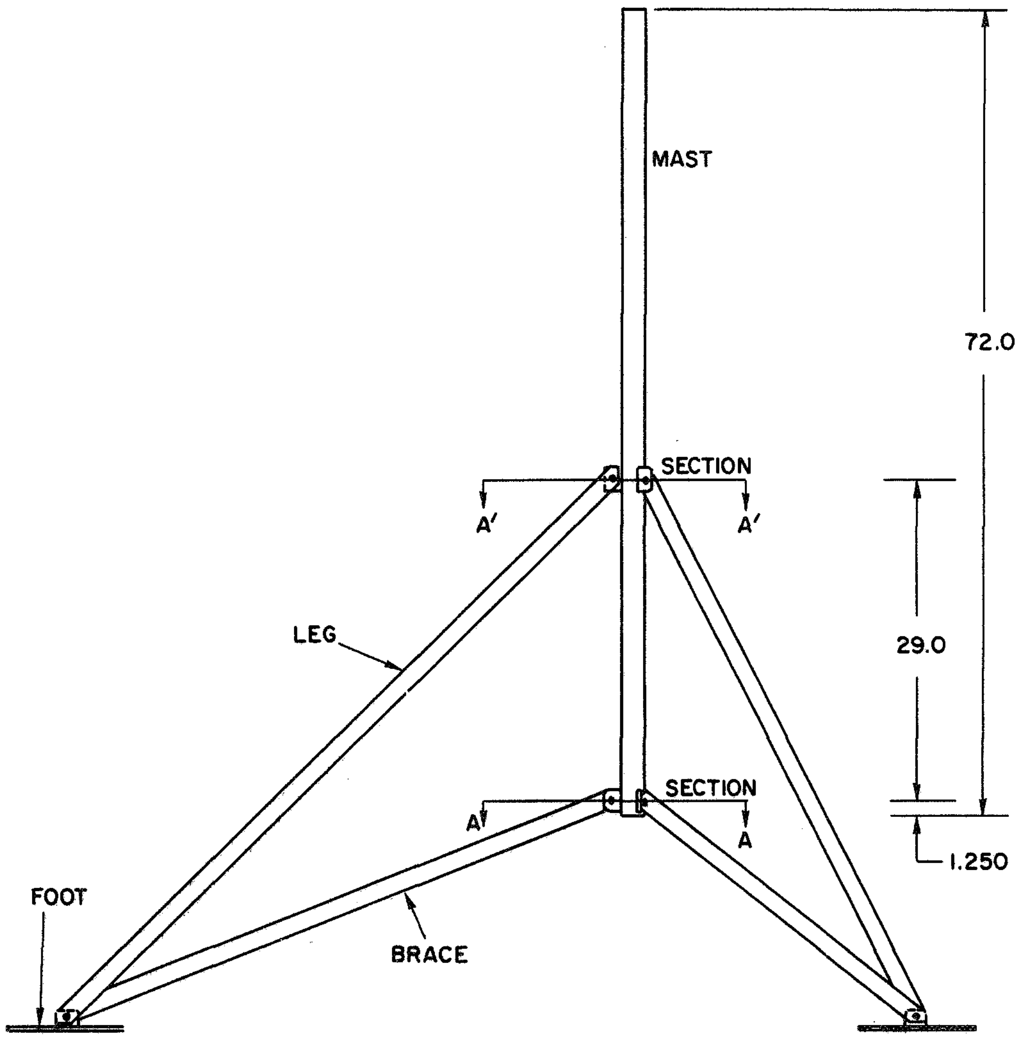


Fig. 21. TRIPOD ASSEMBLY.

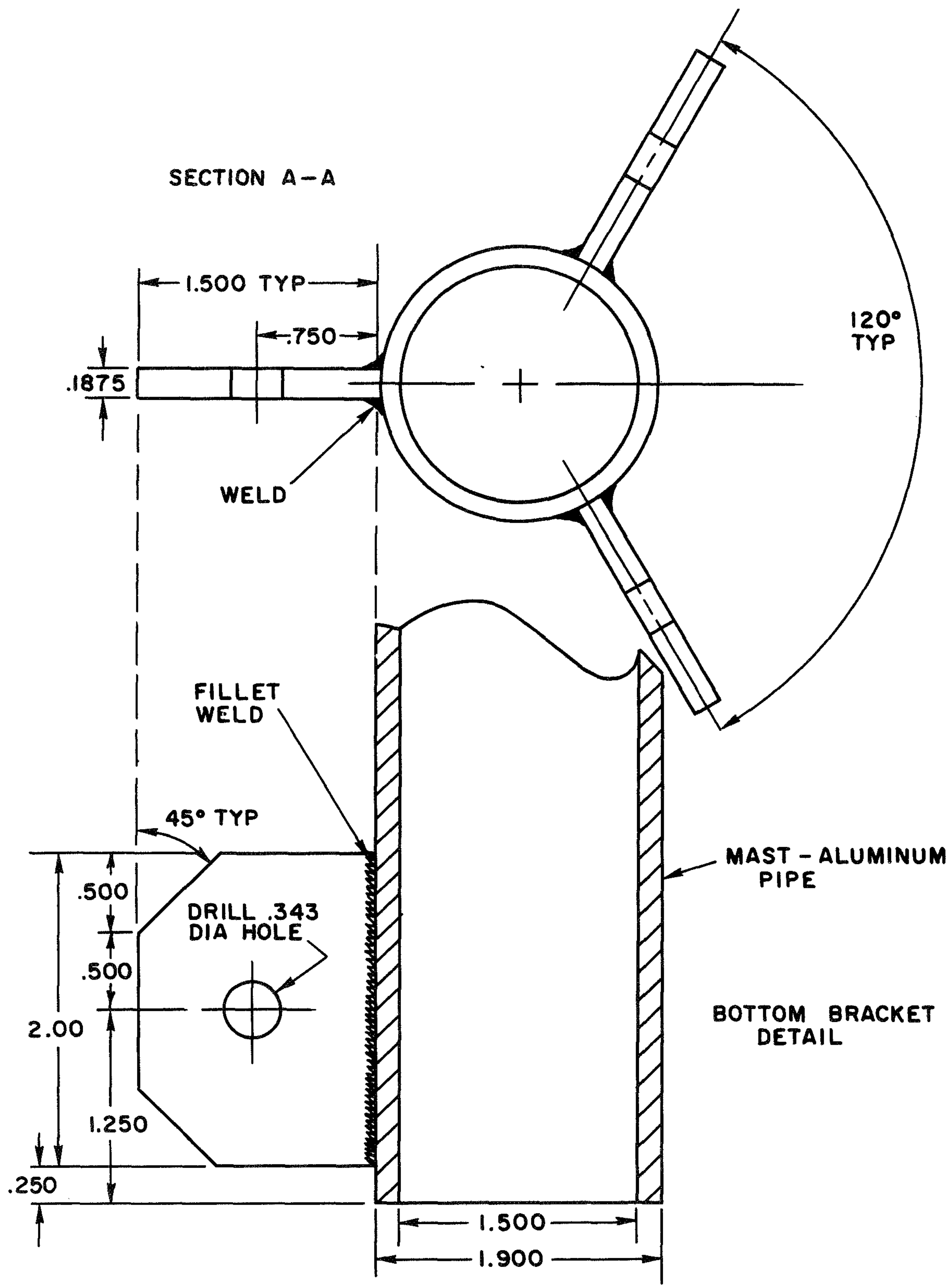
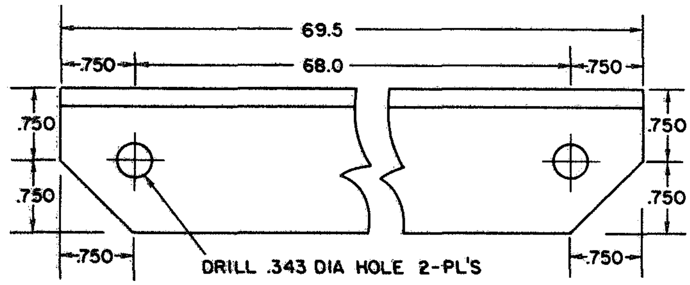
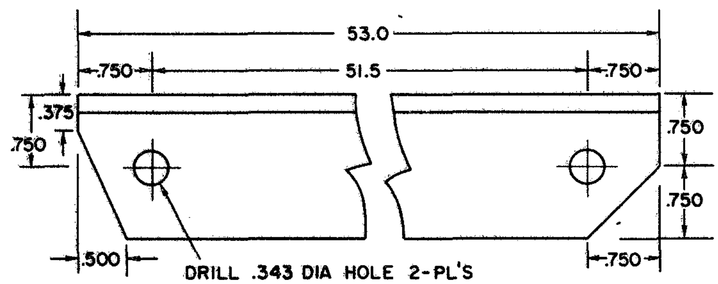


Fig. 22. TRIPOD-MAST BRACKETS.



a. Leg detail, 3 required



b. Brace detail, 3 required

Fig. 23. TRIPOD LEGS AND BRACES

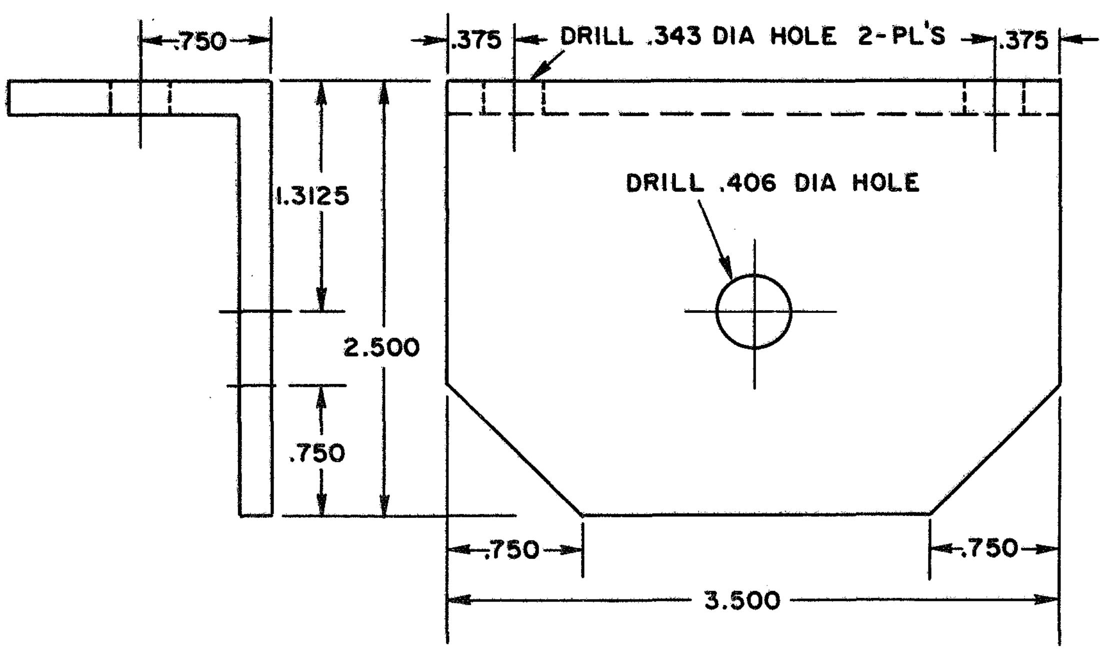


Fig. 24. TRIPOD-HEAD ANGLE.

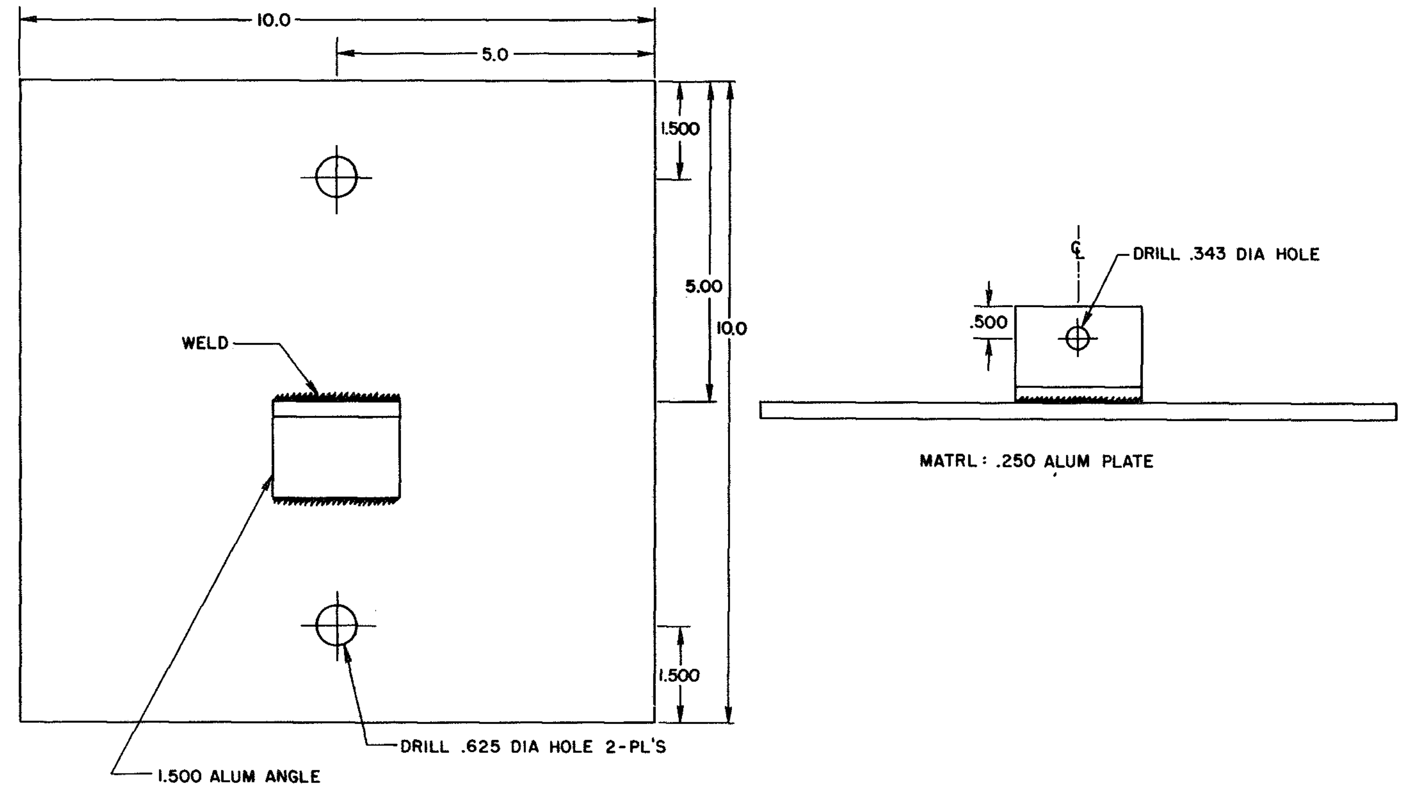


Fig. 25. TRIPOD FOOT.

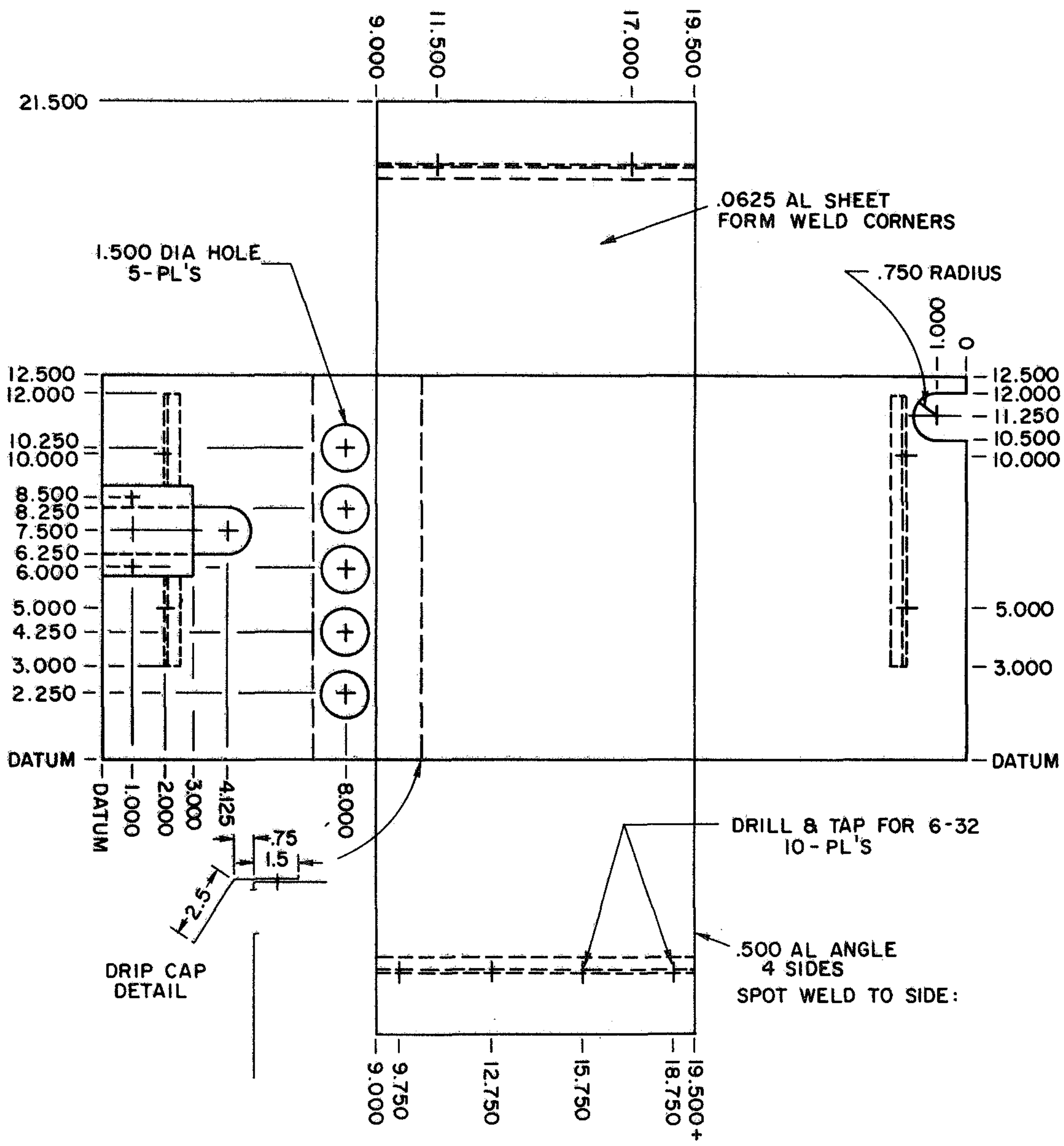


Fig. 26. ROTATOR COVER.

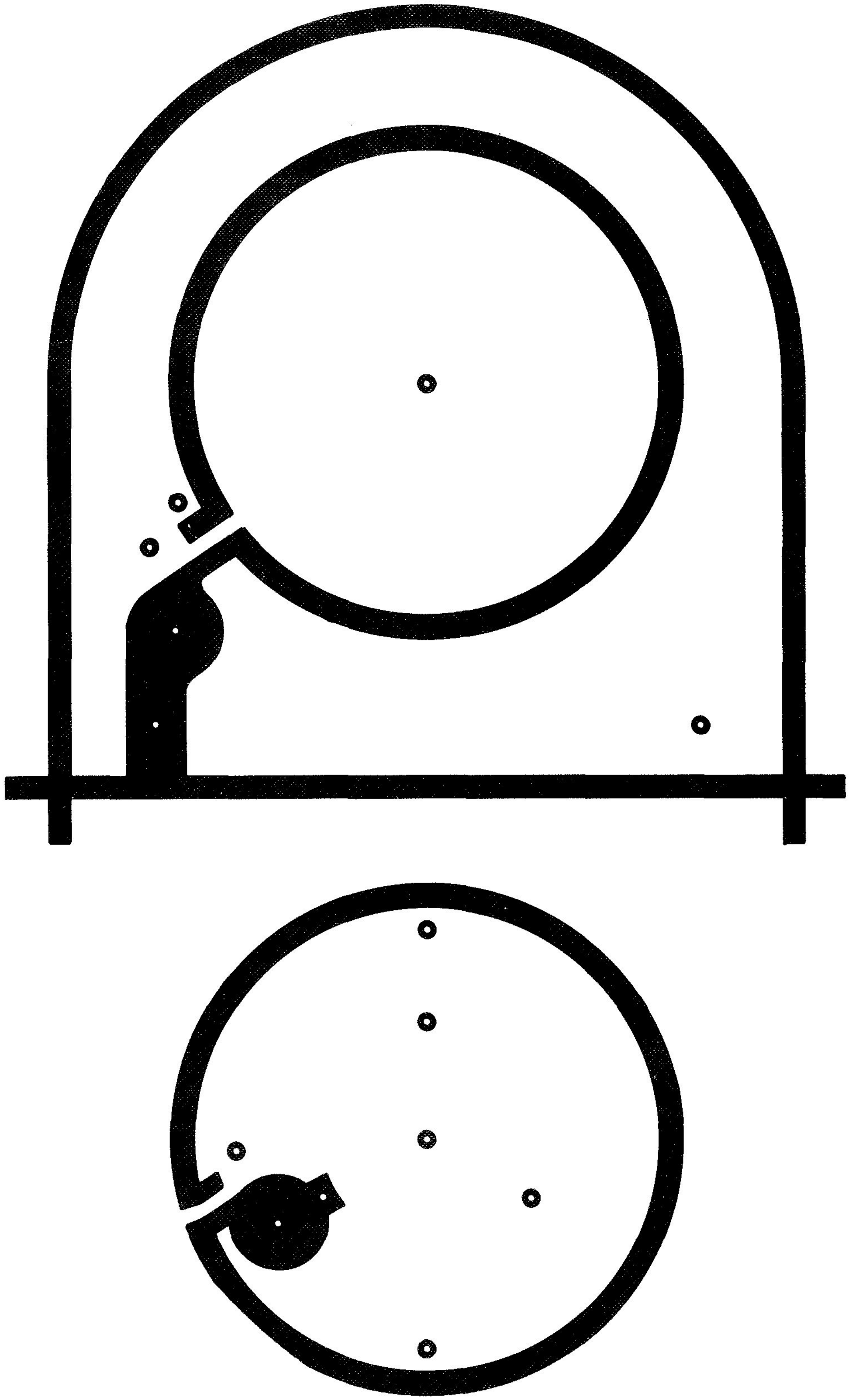


Fig. 27. ROTARY-JOINT PRINTED-CIRCUIT LAYOUT.

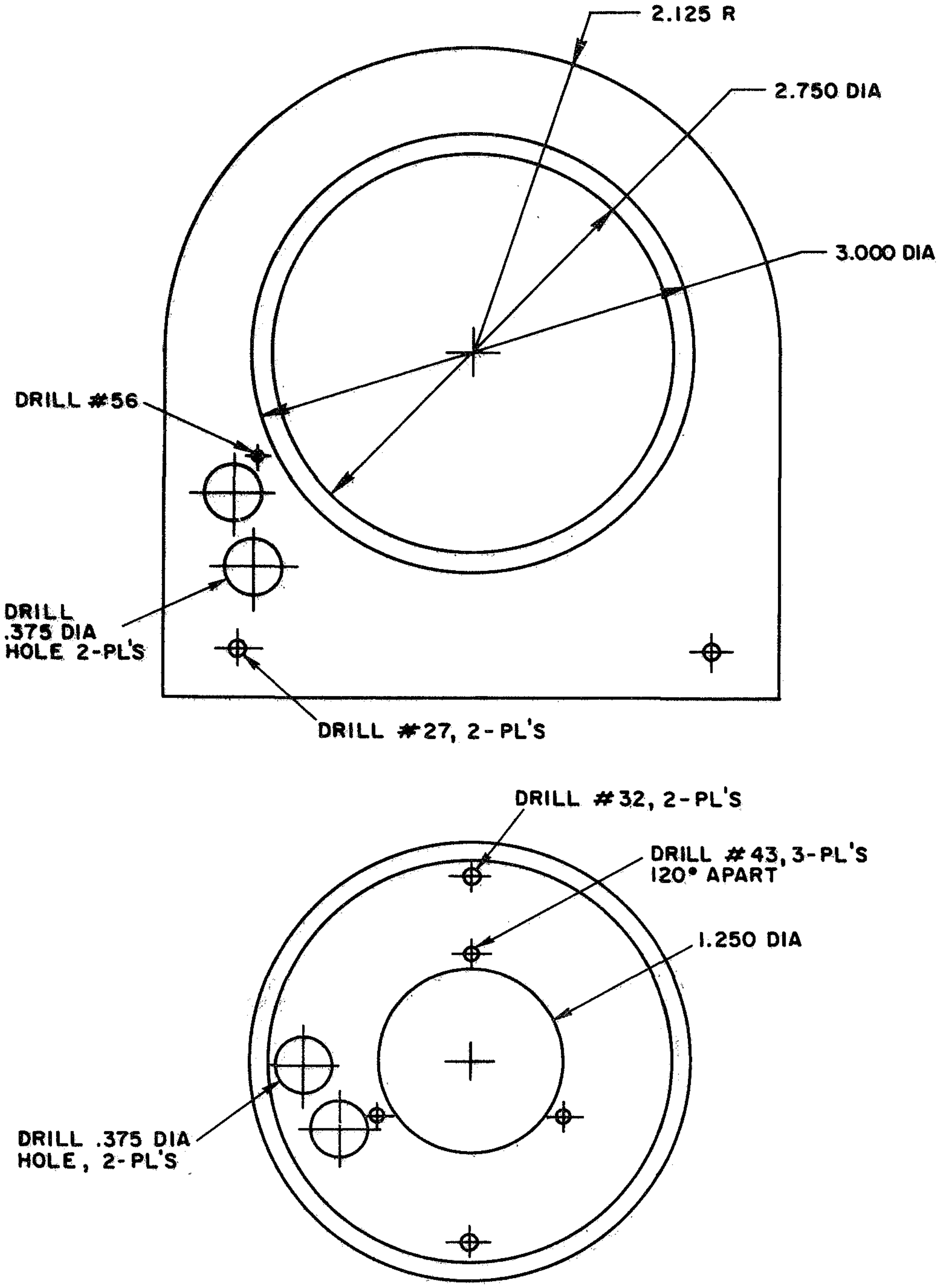


Fig. 28. ROTARY-JOINT DRILLING INFORMATION.

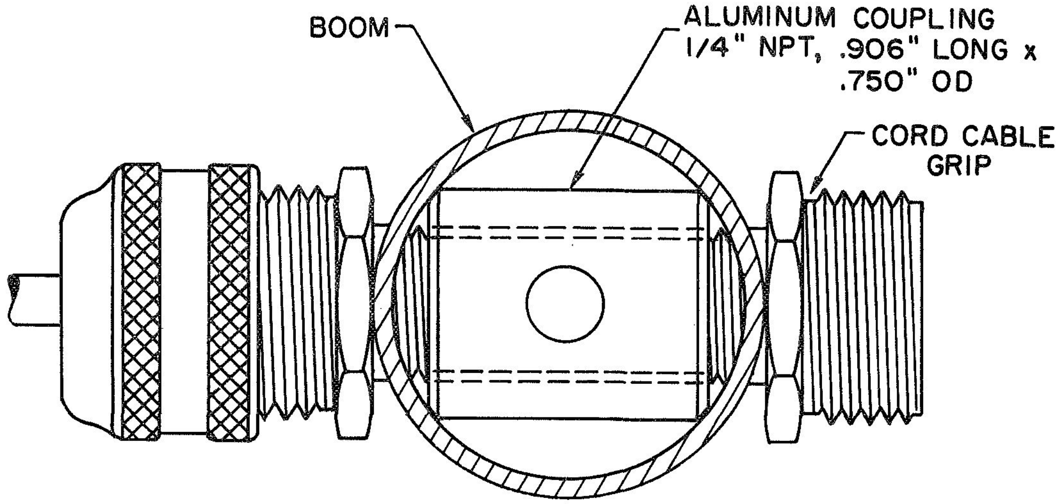


Fig. 29. PARASITIC-ELEMENT FITTING ASSEMBLY.

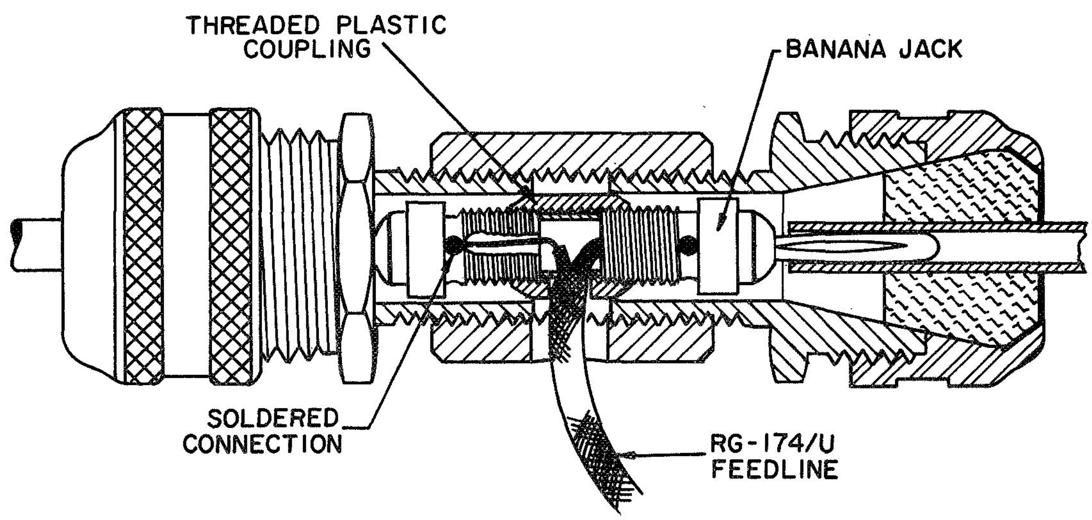


Fig. 30. DRIVEN-ELEMENT FITTING ASSEMBLY.

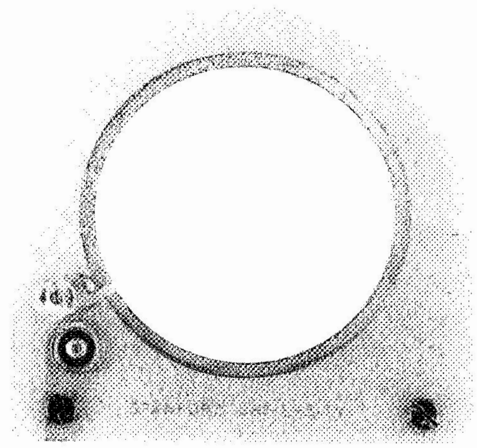


Fig. 31. ROTARY JOINT,
FIXED HALF.

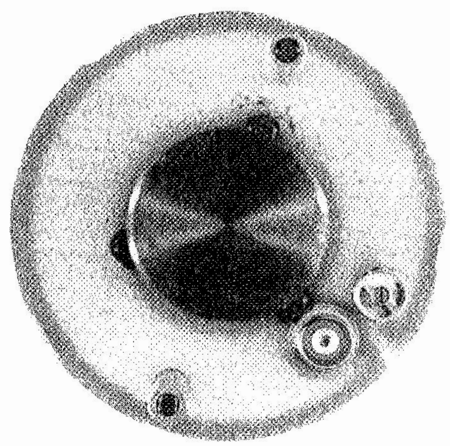


Fig. 32. ROTARY JOINT, ROTARY
HALF-FRONT.

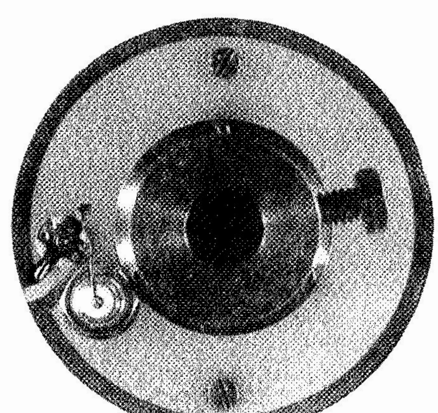


Fig. 33. ROTARY JOINT, ROTARY HALF-REAR.

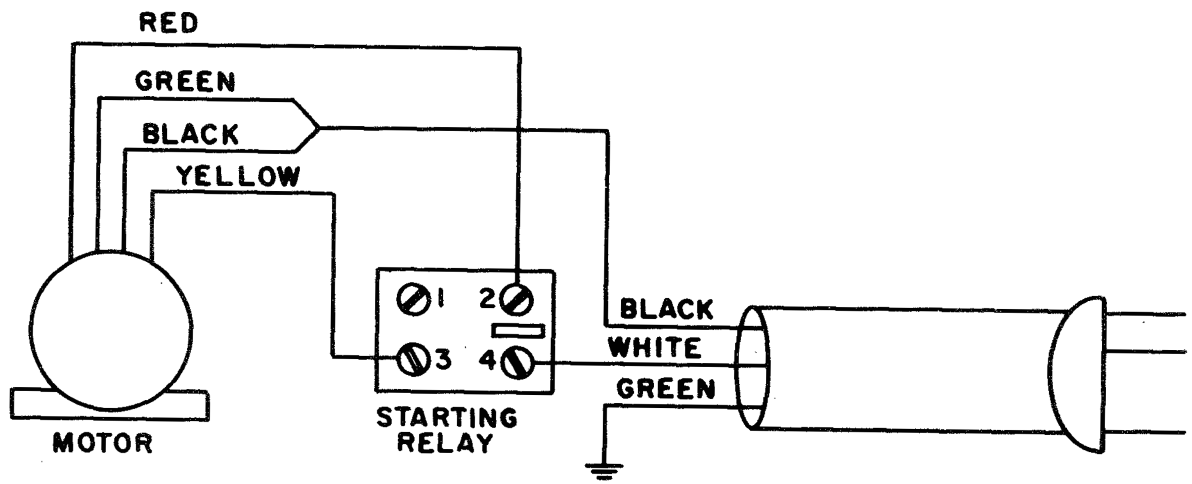
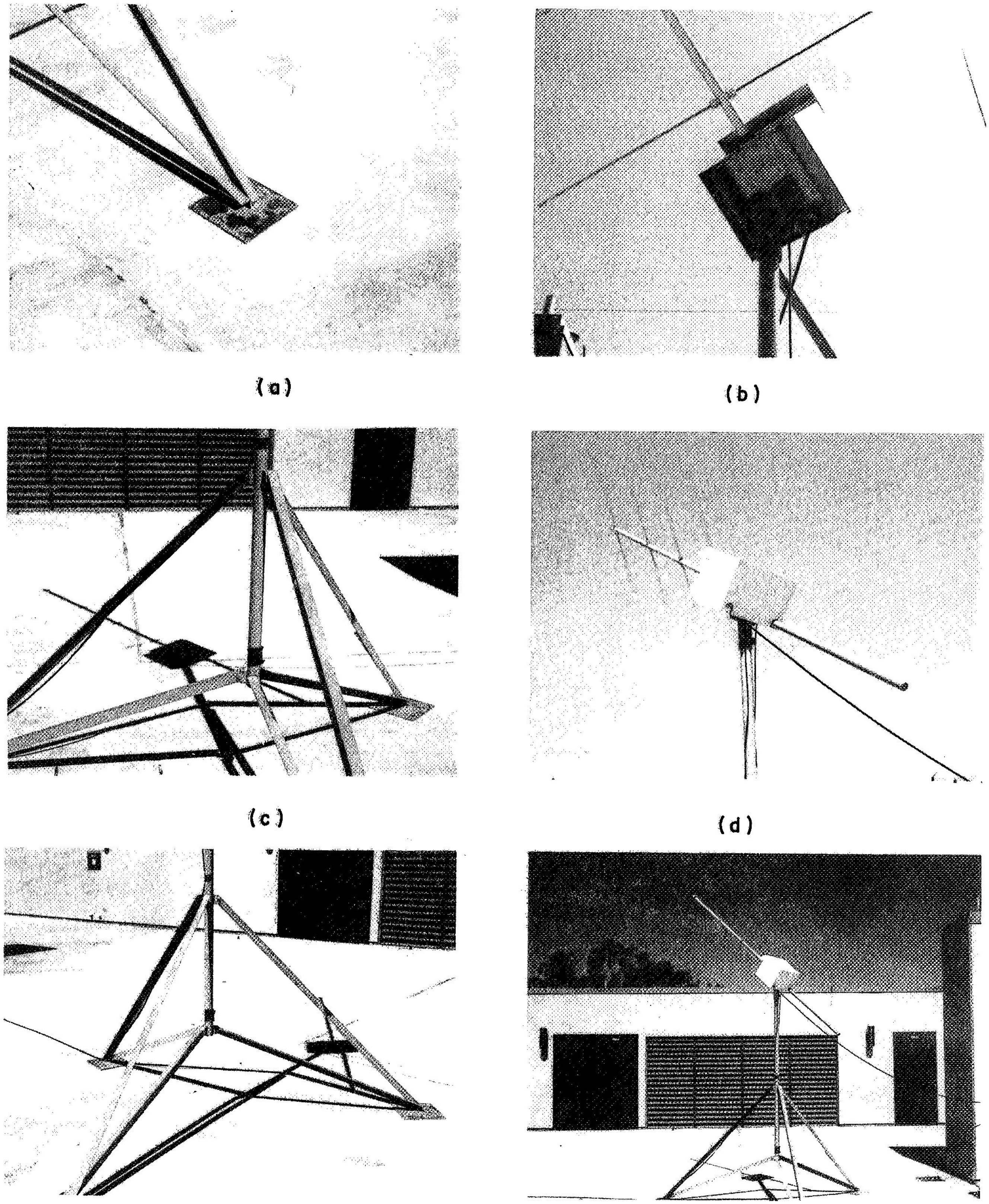


Fig. 34. MOTOR-RELAY WIRING,



(a) (b)

(c) (d)

(e) (f)

Fig. 35. ANTENNA-STRUCTURE DETAILS.

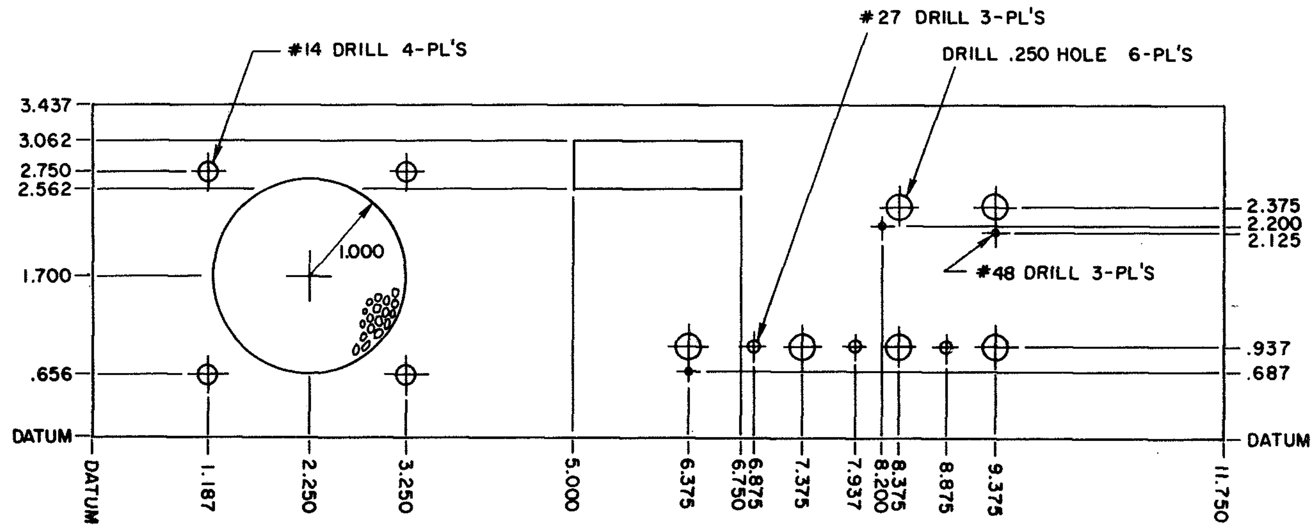


Fig. 36. FRONT-PANEL LAYOUT.

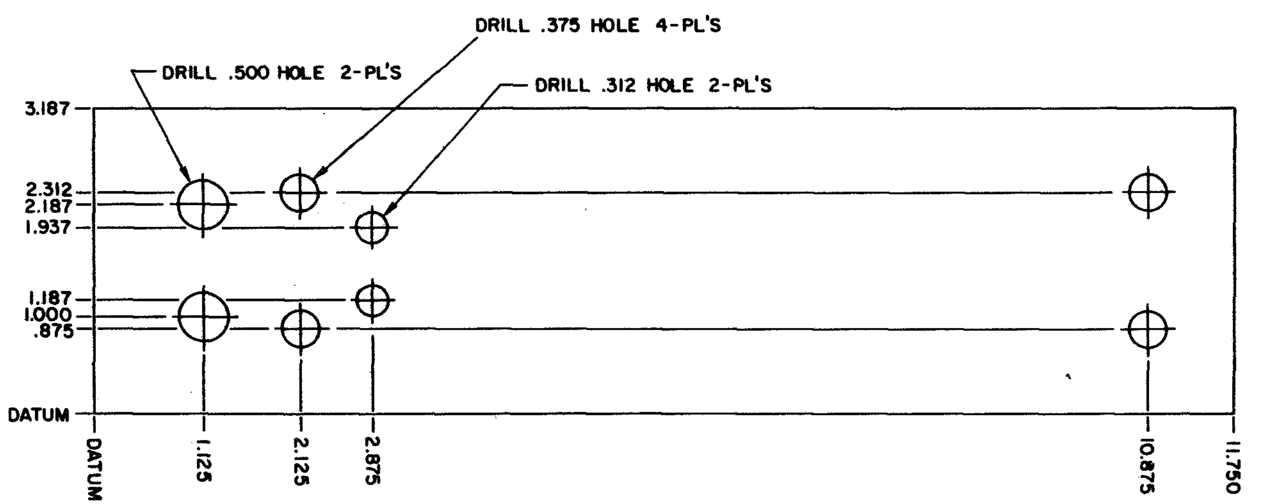


Fig. 37. REAR-PANEL LAYOUT.

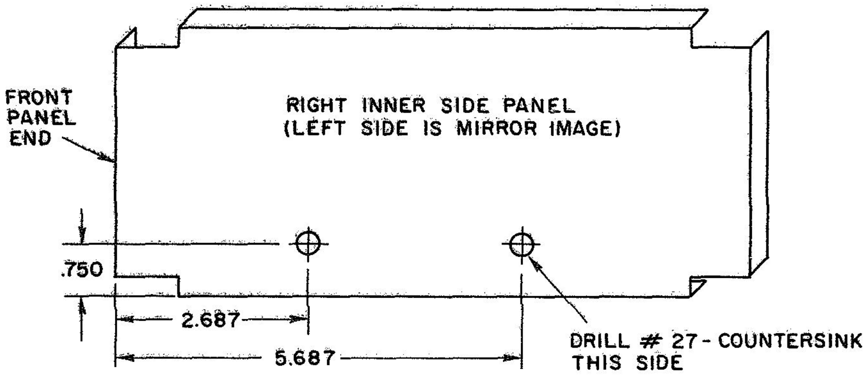


Fig. 38. INNER SIDE-PANEL LAYOUT.

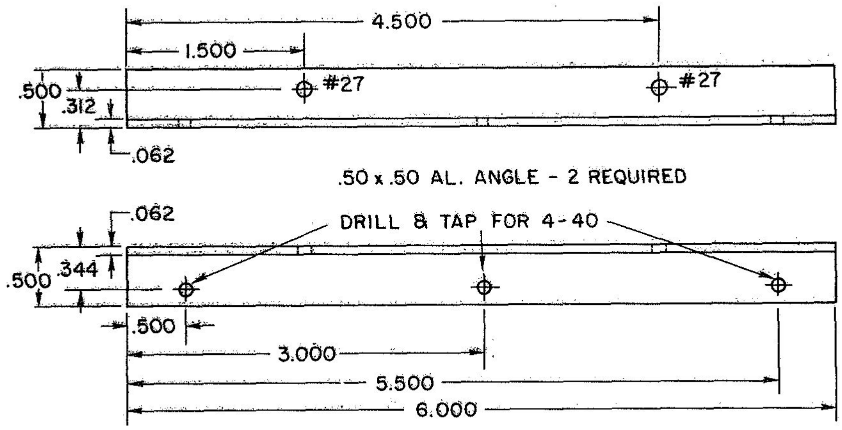


Fig. 39. RECEIVER-BOARD MOUNTING BRACKET.

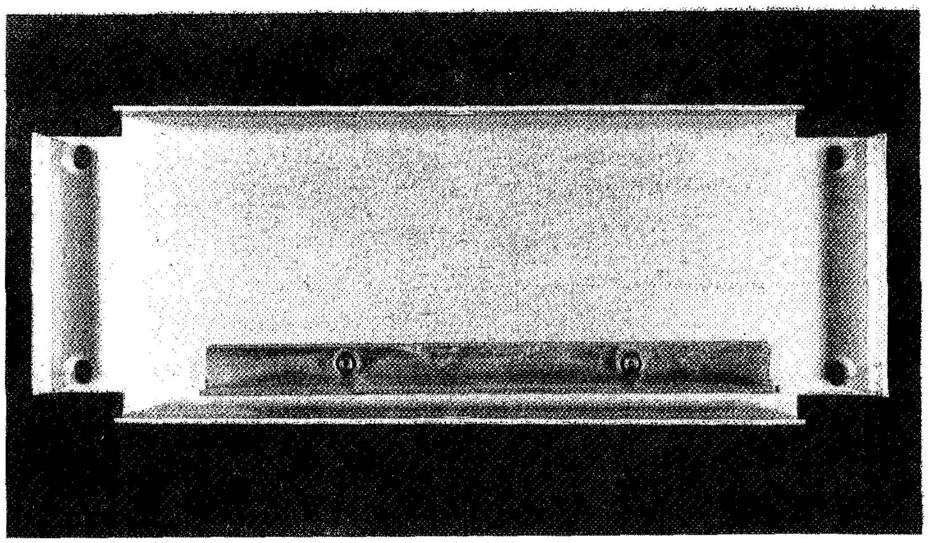


Fig. 40. INNER SIDE PANEL WITH BRACKET.

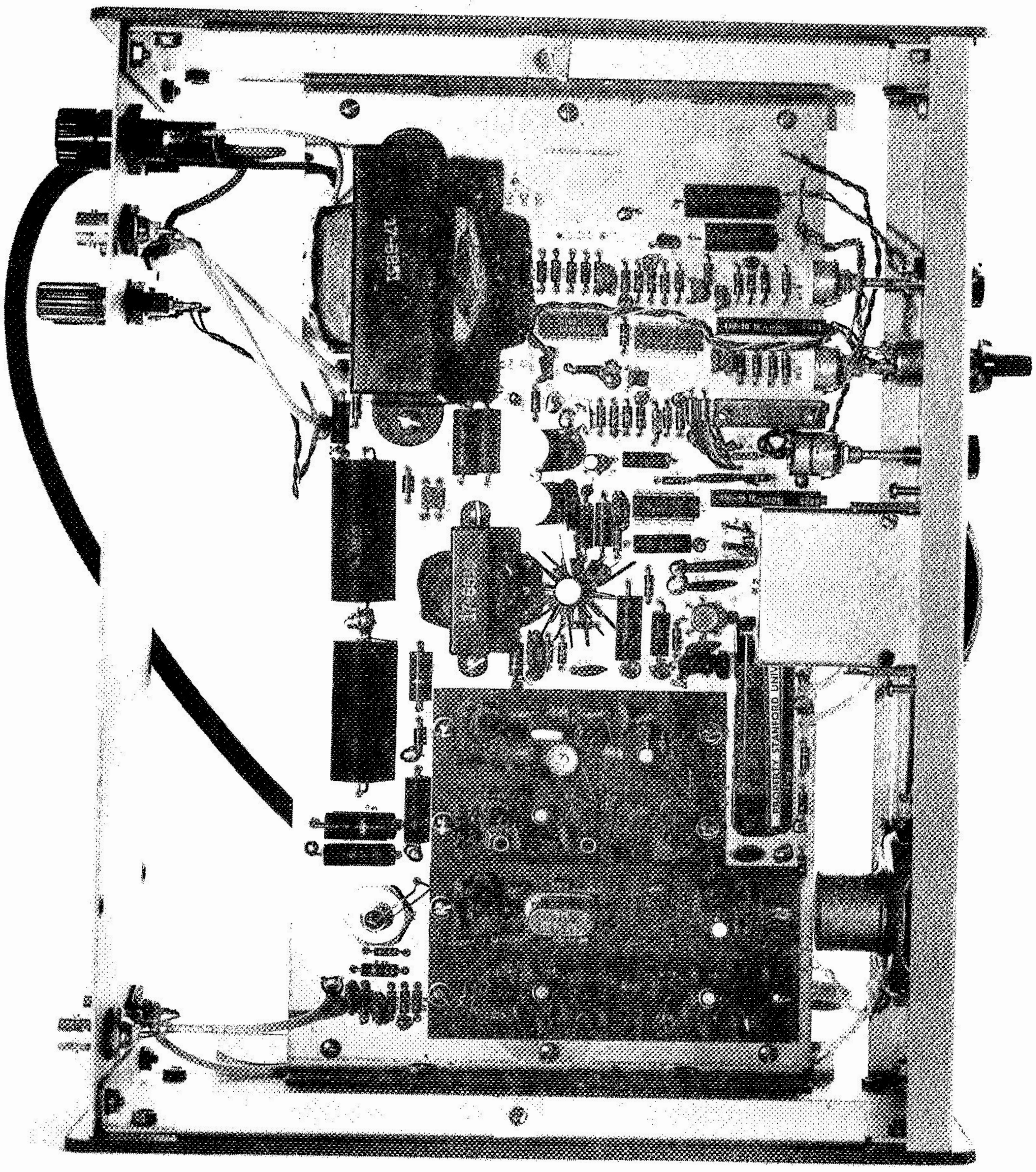
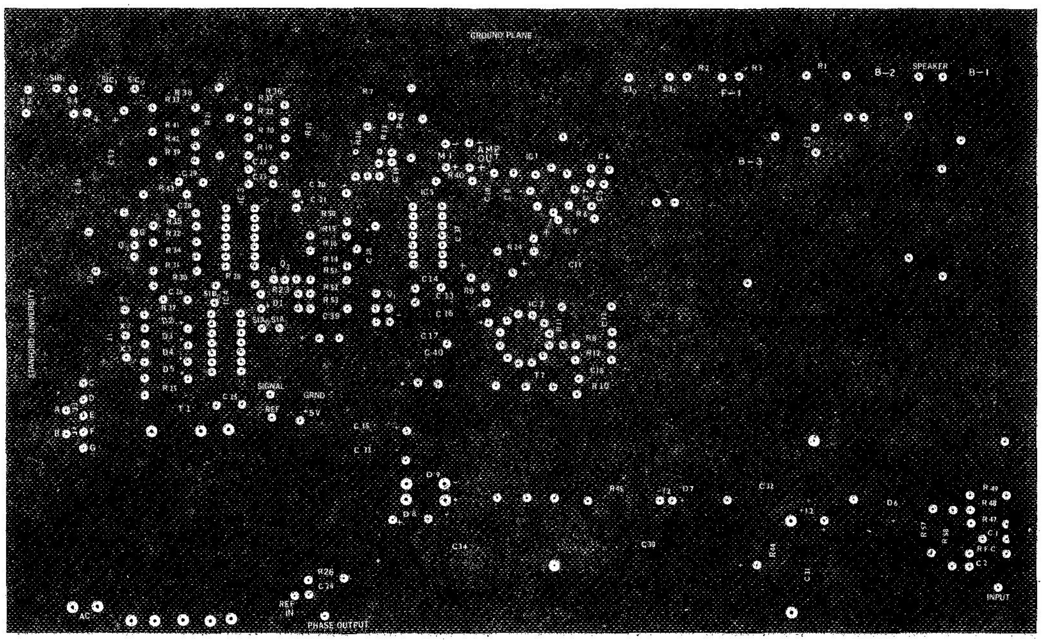
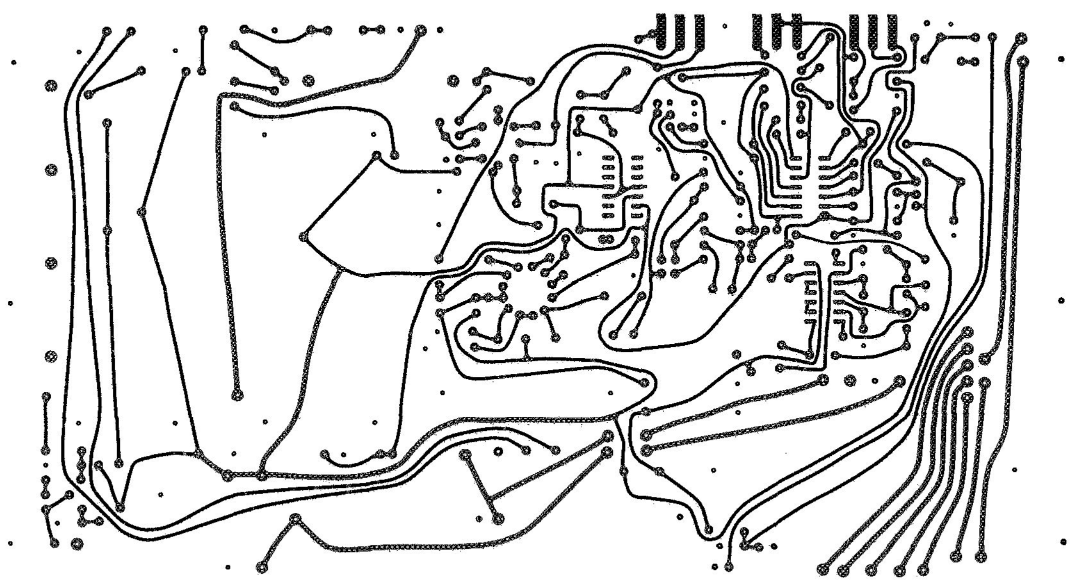


Fig. 41. RECEIVER/PHASE-METER BOARD.



a. Top



b. Bottom

Fig. 42. RECEIVER/PHASE-METER PRINTED-CIRCUIT LAYOUTS. Half size.

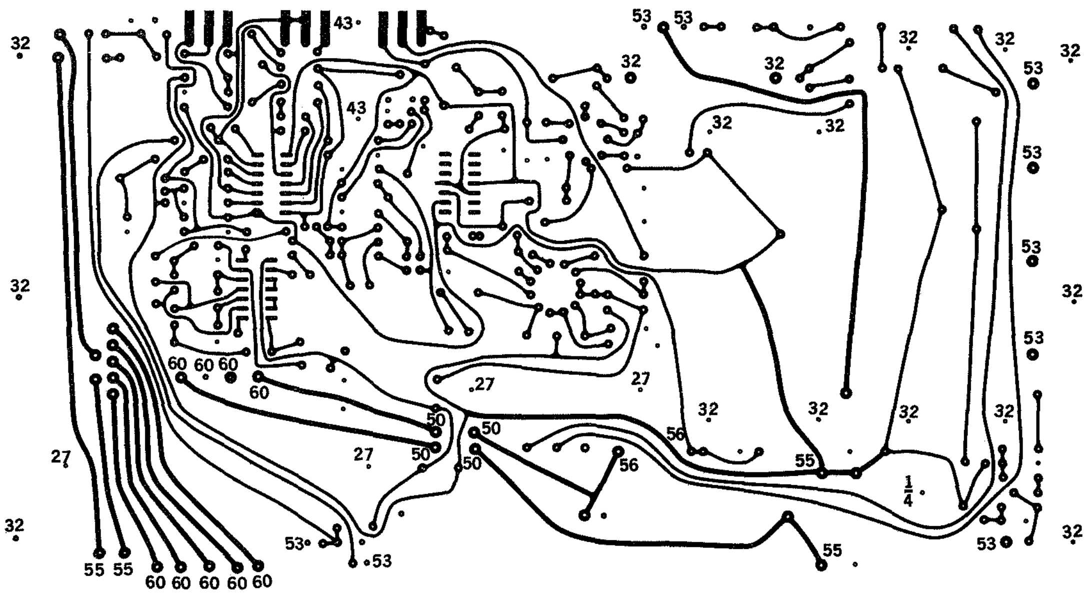


Fig. 43. PRINTED-CIRCUIT DRILLING INFORMATION.
All unmarked holes, #64.

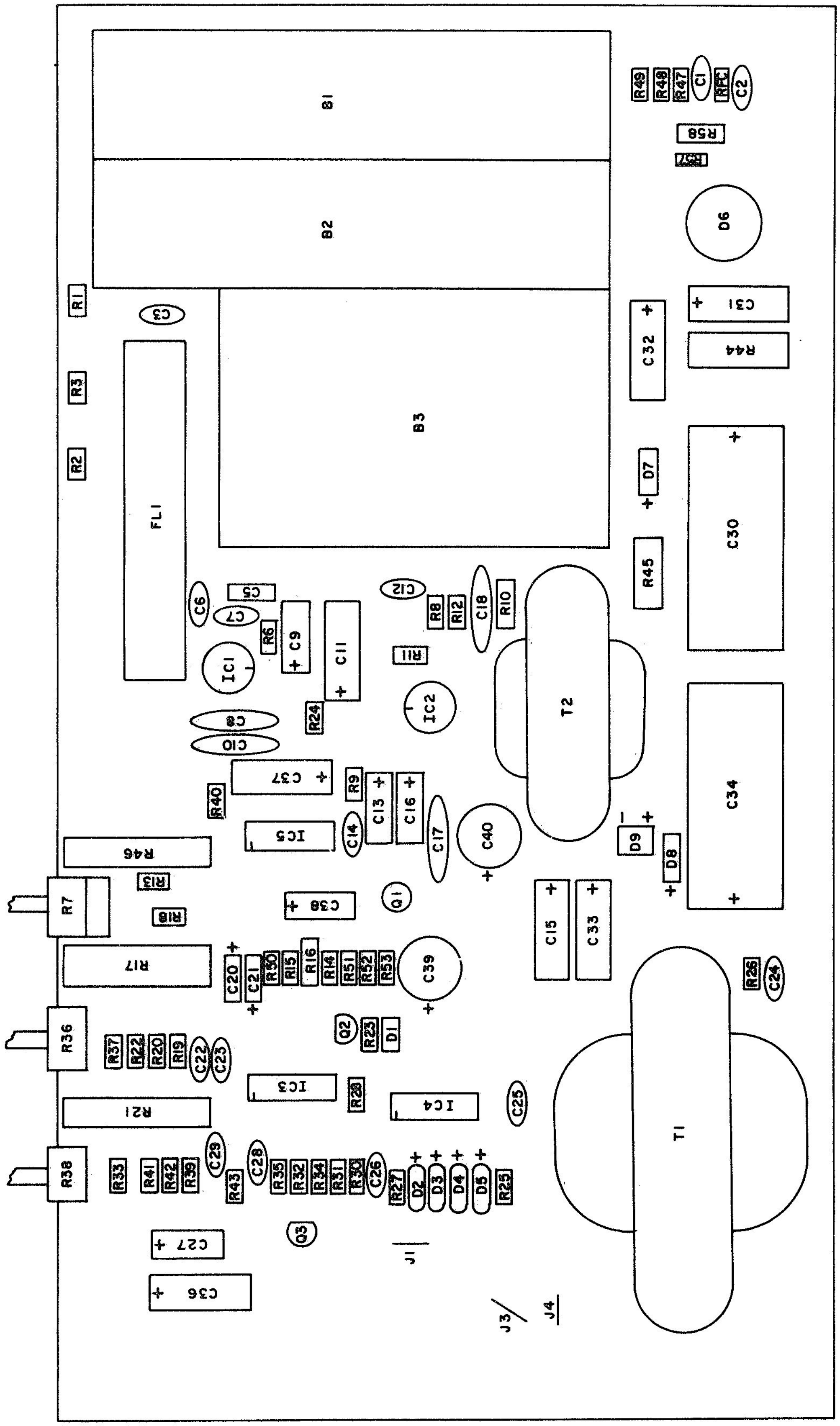


Fig. 44. PRINTED-CIRCUIT PARTS PLACEMENT.

Chapter V

ALIGNMENT

A. Power Supplies

At initial turn-on, the first item that should be checked is the power-supply voltages which are measured at the outputs of the respective zener diodes according to

nominal voltage	measurement point	acceptable value
12 V dc	cathode of D6	10.5 to 13.0 V dc
-12 V dc	anode of D7	-10.5 to -13.0 V dc
5 V dc	anode of D8	4.0 to 6.0 V dc

If the signal-level meter is observed to be off scale in either direction, R46 should be adjusted through the front-panel access hole to bring the meter back on scale. Final adjustment will be accomplished later.

The voltage drop, measured across R44, should fall between 5.5 and 6.5 V dc. If it is outside these values, low or high line voltage is indicated and can be compensated for by changing jumpers J3 and J4 according to the transformer data sheet.

B. Receiver

If S3 is in the WWV position, advancing the volume control should produce receiver noise; changing S3 to the VHF position should cause a small increase in noise output. If no noise increase is heard or a very large increase is noted with overload indicated, pad resistors R1, R2, and R3 should be changed to produce the desired results. If a suitable antenna is connected to the WWV antenna connector, a 10 MHz WWV reception should be obtained and an upward indication noted on the panel meter. Slight adjustment of L4 on board B3 can be made for small center-frequency changes.

With S3 set to VHF, R46 is adjusted for a zero panel-meter indication. A 50 Ω coaxial feedline (of a length that will be used in the final installation) is connected between the antenna-mounted preamplifier output and the receiver VHF antenna input, a further increase in receiver noise should be heard and the panel meter should move upward a few divisions. For this check, the preamplifier input should be terminated in 50 Ω. If no meter indication is observed or if the meter swings beyond half scale, pad resistors R47, R48, and R49 should be changed.

C. Phase Meter

Alignment of the phase meter primarily consists of tuning the active filter with the remainder to check for proper operation of the other circuitry. This tuning is most easily accomplished by utilizing a variable amplitude function generator; lacking this, however, the reference pulses from the antenna system can be used. In either case, the reference pulses will be employed for the final adjustment so as to match the filter to the individual antenna-rotation rate.

An oscilloscope is connected to the cathode of D1. S3 is set in the WWV position, with no antenna connected to the WWV input, and mode switch S1 is set to the CAL 2 position. The filter may be oscillating at this point, evidenced by a large-amplitude (20 V peak to peak) sinewave output on the scope; if this is not the case, R21 is advanced clockwise until oscillation occurs. The center frequency control R17 is adjusted for a 3 Hz oscillation frequency, and the Q control R21 is slowly decreased until the output amplitude <u>just</u> begins to decrease. Because of the high circuit Q, all adjustments must be made slowly and in small increments to allow ample time for the output to stabilize so as to obtain a valid indication of what has been accomplished. After the output has stabilized, it should be at zero or at a very low level. The function generator, set to 2.9 Hz, is then connected to the junction of R13 and C19.

The generator amplitude is set to obtain a 2 to 4 V peak-to-peak filter output on the scope. R17 is adjusted carefully for maximum output and, as the output approaches 10 V peak to peak, the generator level is reduced. If, at any time, the output increases to a large value, the generator connection should be removed to check for oscillation. If oscillation is present, R21 should again be decreased until the output just begins to decrease. This process should be continued until a maximum-output point is obtained with R17, and R21 is just below the point of oscillation.

If a function generator is not being used, the antenna rotator must be placed in operation; the gearbox must be filled with the correct grade of lubricant. A cable is connected between the antenna reference switch and the receiver/phase-meter reference input. With the rotator in operation, the reference-input connector is checked for 5 V pulses at a 2.91 Hz rate. If pulses are not present or if they occur at half the correct rate, repositioning of the reference-switch bracket is indicated. A 1,000 pF capacitor is connected temporarily between the reference-input connector and the junction of R13 and C19, and R17 and R21 are adjusted, as described above. This method should produce a maximum output of 4 to 6 V peak to peak when properly tuned.

With signals present at both the filter and the reference input, and the mode switch in the operate position, rectangular pulses should be checked at jumper J1. The width of the pulse is dependent on the relative phase of the two inputs and on the phase shift through the active filter. If the mode switch is set in each of the two calibrate positions, the dc level at J1 assumes a steady value equal to that of the maximum and minimum pulse amplitudes. With the mode switch in the CAL 2 position, the dc level should be checked at the phase-output connector; this output should be adjustable to zero, using the balance control R38. With the mode switch in the CAL 1 position, the output may be adjusted over a range of -2 to -10 V, using the level control R36. In normal operation, this procedure is used to calibrate the output at the 0° and 180° levels so as to cover the desired amount of recorder-chart span.

D. Polarization Calibration

To measure absolute polarization, the complete system must be calibrated, using a reference dipole and a signal generator. It is desirable, however, first to place the complete system in operation, relying on the satellite to provide an indication of the normal operating signal level. After this is obtained, the antenna boom is swung to a horizontal position, pointing at a vertical-reference dipole located approximately 30 ft away. The signal-generator level is adjusted into the reference antenna to obtain the same signal-strength indication from the receiver as was seen when observing the satellite. The phase meter is connected to a recorder or voltmeter and the two end points are calibrated. The output level then seen, with the mode switch in operate, represents the measured polarization angle.

The reference used at Stanford is that vertical polarization equals 90° as measured by the phase meter, which is midway between the two calibrated end points. Adjustment is effected by rotation of the antenna boom on the shaft-to-boom coupling.

Chapter VI

OPERATION

A. Siting

The choice of an operating location is dependent on a number of factors. Ionospheric studies requiring data from a given raypath or subionospheric point impose the prime constraint on the selection of a site; determination of the ground location and look angles required is presented in the Appendix. When the general area is determined, consideration should be given to a specific site that provides a clear view of the satellite to minimize reflection problems and an absence of man-made noise generators (power lines, busy highways, rotating machinery, etc.). Advantage can be taken of existing shielding, such as buildings and hills, by placing the antenna in front of them. Improved stability will result if the receiver/phase meter is installed in a room-temperature environment.

B. Antenna

After erection of the antenna assembly and final placement, the tripod feet should be anchored, using 18 in. stakes if the prevailing wind velocities are high. Orientation of the antenna to the proper look angles is accomplished with a compass (correcting for magnetic variation) and an elevation transit or protractor and level. The gearbox oil level should be checked prior to antenna rotation.

C. Receiver

With the antenna in operation and interconnecting cables installed, the satellite should be heard in the receiver. Slight adjustment of L4 on board B3 may be necessary to center the signal in the receiver passband. The necessity of this adjustment is dictated primarily by the accuracy of the crystals used in the two conversion oscillators. If the signal-strength meter indicates a very low level or overload, pad resistors R47, R48, and R49 should be changed. Normal meter levels are between

1 and 5. If WWV reception is to be utilized, a suitable 10 MHz antenna should be erected and connected to the receiver.

D. Phase Meter

The following factors must be considered when selecting a strip-chart recorder:

(1) a full-scale sensitivity between 1 and 10 V

(2) a chart speed between 1 and 6 in./hour, dependent on time-resolution requirements

(3) good constant speed characteristics and/or provisions for external timing signals

(4) two channels, if amplitude recording is desired (a floating input is necessary for amplitude recording)

(5) a reliable writing system

The output sense of the phase meter may be changed in two ways. If the recorder has a floating input, the input connections are reversed; if a fixed-input recorder is used, jumper J1 is changed to the other position. J1 is located on the mother board, and its two connections are X1 to X2 or X1 to X3.

The phase meter is calibrated by placing the mode switch in the two calibrate positions and adjusting the level and balance controls to place the recorder pen at the desired end points on the chart. If jumper J1 is connected between X1 and X3, the balance control is adjusted when the mode switch is in the CAL 2 position and the level control is used when in the CAL 1 position. When J1 is connected between X1 and X2, the two controls are adjusted when in the opposite CAL positions. This adjustment procedure should be repeated several times because the two controls interact. The time-constant switch should be left in the low position for the best record detail; however, in the case of extreme noise, a better record will be produced by using the H1 position.

E. Timing

Record-timing information is almost as important as the data. Obtaining accurate and frequent time information on the chart should be emphasized. A problem arises when the primary power fails or the recorder paper jams because the relationship of chart length to real time is lost. Dependence on the recorder constant-speed characteristics is satisfactory if frequent time data are placed on the chart manually or by a reliable automatic system; if power outages are infrequent and the recorder proves to be reliable, once-a-day time marks are sufficient. Accuracy of manually placed time marks may be ensured by use of the WWV reception capability of the receiver.

Chapter VII

FUTURE DEVELOPMENT

Field use of this system has indicated the need of additional development in the following areas.

(1) An accessory is needed to provide automatic calibration at regular intervals to enable the user to account for small shifts in phase calibration and to furnish additional timing information for extended unattended operation.

(2) A phase meter with an input range of 3000° would be expedient to supply an unambiguous diurnal record.

(3) A digital recording system would be advantageous to allow direct computer processing of large amounts of data.

Chapter VIII

PARTS LIST

A. Antenna System

Designation	Quantity	Description	Manufacturer Model/Type
Antenna boom	66"	1-1/4" OD .049 wall aluminum tube	
Antenna elements	158"	1/4" OD .049 wall aluminum tube	
Element fittings	8 ea	Cord-cable grip	Pyle National #DB44316
Fitting coupling	4 ea	1/4" NPT aluminum coupling 3/4" OD × 7/8" long	
Drip ring	1 ea	4-1/2 × 4-1/2 × .062 brass sheet	
Drip-ring collar	3/4"	1-1/2" OD .125 wall brass tube	
Shaft/boom coupling	3-5/8"	1-5/8" OD brass rod	
Rotary-joint bracket	4-1/4"	1" × 1/2" × .125 aluminum angle	
Reference switch bracket	1 ea	1" × 2-3/8" × .040 aluminum sheet	
Rotator plate	1 ea	10" × 10-1/2" × .250 6061-T6 aluminum plate	
Ventilation screen	1 ea	3" × 10-1/2" × .050 perforated aluminum sheet	
Mounting head	8-1/2"	2" IPS aluminum pipe	
Mounting-head ears and plugs	1 ea	6" × 2" × .250 aluminum plate	
Tripod mast	72"	1.9" OD - 1.5 ID 6061-T6 aluminum pipe	

Designation	Quantity	Description	Manufacturer Model/Type
Tripod legs and braces	367-1/2"	1-1/2" × 1-1/2" × 3/16" aluminum angle	
Tripod-mast brackets	6 ea	1-1/2" × 2" × 3/16" aluminum plate	
Tripod-head angles	7"	1-1/2" × 2-1/2" × 3/16" aluminum angle	
Tripod foot	3 ea	10" × 10" × .250 aluminum plate	
Tripod-foot brackets	6"	1-1/2 × 1-1/2 × 3/16" aluminum angle	
Rotator cover	1 ea	30-1/2 × 28-1/2 × .062 aluminum sheet	
Cover brackets	36"	1/2" × 1/2" × .062 aluminum angle	
Cover drip cap	1 ea	4-3/4" × 12-1/2" × .062 aluminum sheet	
Cover weather plate	1 ea	3" × 3" × .062 aluminum sheet	
Positioning arm	42"	1-1/4" OD - .125 wall aluminum tube	
Antenna clamp	1 ea	1-1/4" stainless-steel hose clamp	
Boom-end cap	1 ea	1-1/8" snap plug	
Rotator	1 ea	1/12 HP motor with integral 20:1 gear box	Boston Ratiomotor M109-20-AAS
Reference switch	1 ea	SPST reed switch	Hamlin MRR-2-185
Actuating magnet	2 ea	permanent magnets	Hamlin H-33-606
Magnet carrier	2 ea	1/4" OD × 1" #4 threaded brass spacers	
Switch housing	1 ea	1/4" OD × 1/8" ID × 1" Bakelite spacer	
Switch clamp	1 ea	1/4" plastic-cable clamp	

Designation	Quantity	Description	Manufacturer Model/Type
Switch connector	1 ea	BNC panel connector	Amphenol 74868
Rotary joint	31 in.^{2}	1/8" G-10 copper-clad laminate	
Joint connectors	2 ea	BNC panel connector	Amphenol 74868
Joint capacitors	2 ea	15-60 pF ceramic trimmer	Erie 538-016-P3PO-112R
Antenna feedline	36"	RG-174/U coaxial cable	
Interconnecting cables	36"	RG-55/U coaxial cable	
Cable connectors	4 ea	BNC crimp-type for RG-55/U	Amphenol 309-36875
Feedline connector	1 ea	BNC for RG-174/U cable	Amphenol 69475
Cable connectors	2 ea	Type "N" for RG-55/U	Amphenol 34027
Cable feedthrough	2 ea	Type "N" bulkhead adapter	Amphenol 91100
Line cord	1 ea	3 wire #16 line cord 10 ft	
Line-cord clamp	1 ea	Threaded conduit-cable clamp	
Preamplifier	1 ea	Dual-gate MOSFET-type for 137 MHz	Vanguard Laboratories
Preamplifier brackets	2 ea	1/2" × 1/2" steel angle brackets	
Preamplifier power choke	1 ea	.47μh molded AF choke	Nytronics DD-47
Preamplifier dc blocking	1 ea	.001 μF disk ceramic capacitor	CRL DD-102

B. Receiver/Phase Meter

Designation	Description	Manufacturer Model/Type
B1,B2	VHF converter, 137.35 to 10.00 MHz	Vanguard Model 407
B3	HF converter, 10.00 to .455 MHz	Vanguard Model 306
C1	.001 μF disk ceramic capacitor	CRL-DD-102
C2	Same as C1	
C3	130 pF dipped silver-mica capacitor	CDE CD7CD131G03
C4	Not used	
C5	330 pF dipped silver-mica capacitor	CDE CD15FD331J03
C6	Same as C3	
C7	.01 μF disk ceramic capacitor	CRL DD-103
C8	.1 μF 20 V disk ceramic capacitor	CRL UK-20-104
C9	1 μF 25 V electrolytic capacitor	Sprague TL-1200
C10	.2 μF 20 disk ceramic capacitor	CRL UK-20-204
C11	25 μF 16 V electrolytic capacitor	Sprague TL-1157.1
C12	Same as C7	
C13	5 μF 16 V electrolytic capacitor	Sprague TL-1152
C14	Same as C7	
C15	Same as C11	
C16	Same as C13	
C17	Same as C8	
C18	Same as C8	
C19	Same as C8	
C20	1 μF 35 V tantalum capacitor	Sprague 150D-105-903-AZ

Designation	Description	Manufacturer Model/Type
C21	Same as C20	
C22	500 pF disk ceramic capacitor	CRL DD-501
C23	50 pF disk ceramic capacitor	CRL-DD-500
C24	.05 μF 20 V disk ceramic capacitor	CRL UK-20-503
C25	Same as C7	
C26	Same as C7	
C27	50 μF 12 V electrolytic capacitor	Sprague TL-1133
C28	Same as C22	
C29	Same as C23	
C30	500 μF 25 V electrolytic capacitor	Sprague TL-1217
C31	Same as C11	
C32	Same as C11	
C33	Same as C11	
C34	Same as C30	
C35	Not used	
C36	100 μF 16 V electrolytic capacitor	Sprague TL-1162
C37	10 μF 12 V electrolytic capacitor	Sprague TL-1128
C38	Same as C13	
C39	100 μF 15 V electrolytic capacitor	Mallory MTV-100 CF15
C40	300 μF 10 V electrolytic capacitor	Mallory MTV-300 DE10
D1	Silicon diode	Sylvania 1N457A
D2	Same as D1	
D3	Same as D1	
D4	Same as D1	

Designation	Description	Manufacturer Model/Type
D5	Same as D1	
D6	12 V 50 W zener diode	IR 1N311
D7	12 V 1 W zener diode	IR 1N4742
D8	6.8 V 1 W zener diode	IR IN4736
D9	Diode-bridge assembly	Motorola MDA 920-3
F1	AGC 1/4 amp fuse	
FL1	2.1 kHz mechanical filter	Collins F455 FA21
IC1	Integrated IF amplifier	National LM372
IC2	Integrated AF amplifier	RCA CA3020A
IC3	Integrated dual-operational amplifier	Motorola MC 1437L
IC4	Integrated DTL hex inverter	Fairchild DTμL 9935
IC5	Integrated operational amplifier	Fairchild μA 741C
M1	0 to 1 mA edge panel meter	Simpson 1921
Q1	Dual-gate MOSFET	RCA 40673
Q2	FET	Motorola MPF 105
Q3	Same as Q2	
RFC	.47 μH RF choke	Nytronics DD-.47
R1	39 Ω 1/4 W 10% carbon resistor	
R2	Same as R1	
R3	10 Ω 1/4 W 10% carbon resistor	
R4	Not used	
R5	Not used	
R6	1 kΩ 1/4 W 10% carbon resistor	
R7	10 kΩ No. 1 taper potentiometer with SPST switch	Mallory MLC-4AS

Designation	Description	Manufacturer Model/Type
R8	470 kΩ 1/4 W 10% carbon resistor	
R9	4.7 kΩ 1/4 W 10% carbon resistor	
R10	1 Ω 1/2 W 5% carbon resistor	
R11	Same as R6	
R12	180 Ω 1/4 W 10% carbon resistor	
R13	220 kΩ 1/4 W 10Ω carbon resistor	
R14	Same as R13	
R15	3.9 kΩ 1/4 W 10% carbon resistor	
R16	24.3 kΩ 1/8 W 1% metal-film resistor	IRC CEA T-O 24.3 K
R17	50 kΩ/50 kΩ 1/2 W dual-trim potentiometer	Bourns 209L
R18	Same as R16	
R19	1.5 kΩ 1/4 W 10% carbon resistor	
R20	15 kΩ 1/4 W 10% carbon resistor	
R21	1 kΩ 1/2 W 10% trim potentiometer	IRC 450-20
R22	6.8 kΩ 1/4 W 10% carbon resistor	
R23	10 kΩ 1/4 W 10% carbon resistor	
R24	Same as R13	
R25	Same as R23	
R26	Same as R6	
R27	Same as R23	
R28	Same as R13	
R29	Not used	
R30	22 kΩ 1/4 W 10% carbon resistor	
R31	Same as R23	

Designation	Description	Manufacturer Model/Type
R32	22 kΩ 1/4 W 10% carbon resistor	
R33	33 kΩ 1/4 W 10% carbon resistor	
R34	Same as R23	
R35	Same as R19	
R36	100 kΩ No. 4 taper potentiometer	Mallory MLC 15L
R37	Same as R9	
R38	10 kΩ No. 4 taper potentiometer	Mallory MLC 14L
R39	802 Ω 1/4 W 10% carbon resistor	
R40	330 Ω 1/4 W 10% carbon resistor	
R41	Same as R39	
R42	470 Ω 1/4 W 10% carbon resistor	
R43	100 Ω 1/4 W 10% carbon resistor	
R44	20 Ω 5 W 10% power resistor	IRC PW-5
R45	120 Ω 1 W 10% carbon resistor	
R46	Same as R21	
R47	47 Ω 1/4 W 10% carbon resistor	
R48	2.7 Ω 1/4 W 10% carbon resistor	
R49	Same as R47	
R50	Same as R42	
R51	150 kΩ 1/4 W 10% carbon resistor	
R52	82 kΩ 1/4 W 10% carbon resistor	
R53	1.8 kΩ 1/4 W 10% carbon resistor	
R54	Not used	
R55	Not used	
R56	Not used	

Designation	Description	Manufacturer Model/Type
R57	Same as R40	
R58	330 Ω 1/2 W 10% carbon resistor	
S1	3P3P rotary switch	Alcoswitch MRA-3-3
S2	Part of R7	
S3	SPDT toggle switch	Alcoswitch MST-115D
S4	Same as S3	
T1	Power transformer	TRIAD F-91X
T2	Audio-output transformer	TRIAD TY-31X
Cabinet	3-1/2" × 12" × 9" aluminum cabinet	Moduline MCP-3129
Coaxial connectors	BNC panel connectors, 4 ea	Amphenol 74868
+ amplitude connector	Red binding post	Johnson 111-102
- amplitude connector	Black binding post	Johnson 111-103
Binding post		
Alignment plate	Spacing plate for double banana and plug	Johnson 111-20
Board brackets	12" × 1/2" × 1/2" × .062 aluminum angle	
Panel bushing	1/4" OD panel bushing for 1/8" shaft, 3 ea	Smith 184
Control knob	1/8" shaft knob, 3 ea	Smith 2396
Fuse holder	AGC-type fuseholder	Littlefuse 342004
Bushing	Plastic bushing for 3-wire linecord	
IC2 heat sink	Finned heat sink for TO-5 can	Wakefield NF 215
Line Cord	3 wire No. 18 line cord	

Designation	Description	Manufacturer Model/Type
Speaker	2-1/2" square 4 Ω speaker	Quam 25A07
Speaker grill	3" × 3" × .040 perforated aluminum	
Circuit board	6" × 12" × 1/8" G-10 laminate two-side clad with 2 oz copper	
Coaxial cable	36" RG-174/U coaxial cable	

Appendix

ANTENNA POINTING ANGLE AND SUBIONOSPHERIC POINT CALCULATION

To find the subionospheric-point latitude and longitude and the receiving antenna elevation and azimuth, the following sequential steps should be executed.

(1) $\cos k = \cos i \cos j + \sin i \sin j \cos h$

(2) $\sin m = \dfrac{\sin h \sin j}{\sin k} \qquad 90° < m < 180°$

(3) $w = 360° - m$ = antenna azimuth

(4) $n = \left[2g^2 + 2ge + e^2 - \cos k\,(2g^2 + 2ge)\right]^{1/2}$

(5) $\cos x = \dfrac{\sin k\,(g+e)}{n} \qquad x$ = antenna elevation

(6) $p = 180° - m$

(7) $\tan q - \dfrac{\tan d}{\cos p}$

(8) $\sin r = \dfrac{g \cos x}{g + f}$

(9) $s = q + x + r - 90°$

(10) $\cos t = \sin p \cos d$

(11) $\sin y = \sin s \sin t \qquad y$ = subionospheric-point latitude

(12) $\tan u = \tan s \cos t$

(13) $\tan v = \tan p \sin d$

(14) $z = c \pm (v-u)$ = subionospheric-point longitude

where

- a = subsatellite-point longitude
- b = subsatellite-point latitude
- c = receiver-site longitude
- d = receiver-site latitude
- e = satellite altitude
- f = ionospheric height
- g = earth radius = 6370 km
- $h = a - c$
- $i = 90° - d$
- $j = 90° - b$